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Impact of Heavy Metals on the PSII Maximum Efficiency in the Bryophytes *Pohlia drummondii* and *Physcomitrium patens*

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ZUSAMMENFASSUNG

Die zunehmende Konzentration von Schwermetallen in der Umwelt hat das Interesse an Moosen aufgrund ihrer Fähigkeit zur Bioakkumulation sowie ihres Potenzials für das Biomonitoring geweckt. Diese Studie untersucht die Auswirkungen verschiedener Schwermetalle (As, Cu, Fe, Mn und Sb) auf die Moose *Pohlia drummondii* und *Physcomitrium patens*, insbesondere in Bezug auf Veränderungen der maximalen PSII-Effizienz, gemessen mittels Chlorophyllfluoreszenzanalyse. Die Proben wurden über einen Zeitraum von acht Wochen in verschlossenen Petrischalen unter zwei Behandlungsarten kultiviert: In der einen wuchsen die Pflanzen in einem kontaminierten Medium, in der anderen wurden die Pflanzen zunächst in eine kontaminierte wässrige Lösung getaucht und anschließend in einem nicht kontaminierten Medium weiter kultiviert. Die Messungen erfolgten alle zwei Wochen über den gesamten Zeitraum von acht Wochen, ohne die Deckel zu öffnen, um eine externe Kontamination zu vermeiden. Die Ergebnisse zeigen, dass einige Schwermetalle selbst bei gleicher Konzentration toxischer sind als andere, wobei die Stärke der Reaktion von der Pflanzenart, der Art der Kontamination und der Expositionsdauer abhängt.

ABSTRACT

The increase of heavy metal concentration in the environment has sparked an interest in bryophytes for their bioaccumulation capacity as well as biomonitoring potential. This study focuses on the effects of different heavy metals (As, Cu, Fe, Mn and Sb) on the bryophytes *Pohlia drummondii* and *Physcomitrium patens*, specifically in regard to the changes in PSII maximum efficiency thanks to chlorophyll fluorescence analysis. The samples were cultivated for eight weeks in sealed petri dishes under two treatments: in one, the plants grown in a contaminated medium, while in the other, the plants went through an immersion in a contaminated water solution before growing in an uncontaminated medium. The samples were measured every two weeks over a total of eight weeks, without opening the lid to avoid external contamination. The results indicate that some heavy metals are more toxic than others even at the same concentration, with the intensity of the response depending on the species, type of contamination and exposure duration.

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Finally, this work is dedicated to myself, as proof of what I have learned and accomplished during my Master's, and to my parents, who always supported me and loved me.

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INTRODUCTION

Bryophytes are divided into three different phyla: hornworts (Anthocerotophyta), liverworts (Marchantiophyta) and mosses (Bryophyta). With over 12.000 known species mosses are the most diverse, second only to angiosperm in the whole plant kingdom in terms of diversity (Crosby et al., 2000). Most of the early history of bryophytes remains uncertain, however, studies based on molecular analyses and fossil evidence suggest that bryophytes emerged over 450 million years ago, preceding the diversification of tracheophyte (Su et al., 2021).

Often regarded as primitive compared to vascular plants, bryophytes have simply adapted different strategies to manage the inconsistent water availability of terrestrial habitats. Whereas vascular plants evolved specialized structures to reduce their dependence on water availability, bryophytes developed a drought tolerance strategy. They thrive and reproduce during wet periods, while entering a dormant state during dry conditions, suspending both growth and metabolism to endure water scarcity (Proctor, 2008). Therefore, bryophytes have been studied as models to better understand how vascular plants adapt to harsh environments (Oliver, Velten & Wood, 2000).

BRYOPHYTES PHYSIOLOGY

In tracheophytes, water is absorbed from the soil through roots and transported internally to stems and leaves via the xylem. Water loss is regulated at the leaf surface thanks to stomata which penetrate the cuticle, a protective hydrophobic layer that covers the outer epidermis of the leaf.

On the other hand, bryophytes are poikilohydric, meaning they lack the physiological mechanisms to prevent desiccation during drought periods. While bryophytes also possess a protective cuticle like other land plants (Busta, Budke & Jetter, 2016), this barrier is less restrictive towards water exchange, making water absorption easier. This is particularly important since bryophytes lack a vascular and root system for water transportation, leading to water and dissolved minerals being absorbed across the entire surface of the plant.

Bryophytes are characterized by their small size, which is caused by the absence of a vascular system and lignified structures that provide structural support. Such dimensions maximize the surface area-to-volume ratio, facilitating not only the water absorption throughout the whole plant but also increasing the evaporation surface, causing bryophytes to dry quickly in the absence of water. Externally, the water moves thanks to capillary forces between leaves and stems, while once absorbed, it is transported extracellularly by surface tension and intracellularly through the plasmodesmata connecting adjacent cells (Vanderpoorten & Goffinet, 2009).

Overall, bryophytes are extremely dependent on the environment for both water and dissolved substances such as minerals and nutrients. Uptake can come from rainfall, splash water, mist or high humidity conditions (wet deposition), as well as from accumulation on the plant surface of dust and airborne particles (dry deposition).

This method of water and nutrient absorption allows bryophytes to be independent of soil-derived nutrients, making them able to colonize habitats normally inaccessible to vascular plants, such as hard surfaces like rocks, tree bark, or anthropogenic structures. This independence makes bryophytes pioneer species of extreme importance during primary succession, being able to thrive in nutrient-poor environments during the early stages of humus formation and making the habitat more suitable for the subsequent colonization of vascular plants.

BIOACCUMULATION AND BIOINDICATORS

Being sessile organisms, plants cannot escape their environment and must adapt when pollutants accumulate. If adaptation fails, only the species more tolerant or adapted to the new conditions will survive. This process exerts a selective pressure, driving the evolution of various strategies both at an inter-and intraspecific level (Boquete et al., 2021). When in the presence of heavy metal contamination, plants need to adapt to certain strategies to be able to survive and reproduce under such conditions. One option is avoidance, in which specific mechanisms stop the uptake of the contaminants from entering the plant. On the other hand, tolerant species absorb the contaminant and isolate it in cells and tissues characterized by low metabolic activity (Baker, 1987). Among these, some plants are defined as accumulators while others are excluders, with the difference being the level of control in the uptake and the location for storage and detoxification (Baker, 1981).

While most studies have focused on vascular plants, bryophytes are known for their bioaccumulation capacity and overall tolerance to high levels of heavy metals. Moreover, certain species can be considered heavy metal specialists, employing unique adaptations to thrive in contaminated environments. An example of this can be seen with multiple species of the genera *Scopelophila* and *Mielichhoferia*, which have an affinity for copper rich substrates (Aikawa *et al.*, 1999; Boquete *et al.*, 2021).

In bryophytes, the uptake of contaminants can occur in multiple ways. Among these, one of the most common in non-vascular plants is passive absorption, which is based on the attraction between the negatively charged cation exchange sites on the cell walls and the cations present in the environment. When heavy metals are present, they attach themselves to these exchange sites, taking the place of nutrient cations due to their stronger binding affinity (Mahapatra *et al.*, 2019). In contrast, certain mineral elements are actively absorbed through specific transporter proteins located on the cell membrane, facilitating their uptake into the cytoplasm (Yang *et al.*, 2022). Moreover, the uptake of heavy metals can be facilitated by having contaminated water, soil particles, or dust trapped between leaves and other irregular surfaces, prolonging contact time and increasing the likelihood of absorption.

Due to their ability to accumulate heavy metals, bryophytes have been widely used for biomonitoring atmospheric and aquatic pollution. Studies based on this method can help identify pollution sources (Donovan et al., 2016), determine the levels of multiple contaminants in specific areas, and map spatial and temporal patterns of atmospheric contamination over long time periods (Farmer et al., 2002; Frontasyeva et al., 2020).

There are multiple benefits in using bryophytes as bioindicators compared to mechanical instruments. Since these studies are based on naturally occurring plants, the costs are significantly reduced and the needed workforce minimal, even in the case of extensive survey areas. At the same time, the use of plants provides valuable information on the effects of specific contaminations on living organisms. Bryophytes also tend to accumulate heavy metals at concentrations higher than those in the surrounding environment, enabling more robust chemical analyses (Harmens et al., 2008). Unfortunately, despite being used for years, moss survey techniques often lack standardized protocols for sampling and analysis, making comparisons between the results of multiple studies difficult (Fernández et al., 2015).

CONTAMINATION WITH HEAVY METALS

Human activity has deeply influenced the earth, to the point that scientists have proposed a new geological epoch, the Anthropocene (Crutzen & Stoermer, 2000). Various anthropogenic activities release large amounts of harmful substances into the environment, with heavy metals being among the most widespread and concerning due to their harmful effects. This type of pollution poses significant risks to human health, particularly in urban areas where human activity is more intense (Biasioli, Barberis & Ajmonemarsan, 2006). High levels of contamination can lead to the development of various illnesses through indirect ingestion, inhalation or accumulation in water sources and in the food chain (Abrahams, 2002).

Heavy metals accumulate in the environment from both natural and anthropogenic sources (*Figure 1*). Different types of rocks contain multiple heavy metals, which are naturally released into the environment as a product of the weathering process. Once mobilized, these elements are absorbed by vegetation and later introduced into the soil and atmosphere through volatilization or decomposition (Yan et al., 2020). While inputs from natural sources are usually limited, events such as volcanic eruptions or wildfires can release significant amounts of heavy metals into the atmosphere in a short amount of time (Friedland, 1989). Anthropogenic sources, however, are far more frequent and intense, often resulting in dangerous concentrations that render entire areas toxic to many species. Multiple sectors are responsible for emitting heavy metals into the environment, with the most influent being mining, metallurgic and manufacturing industries, transportation, electricity and heat production, petroleum refining, use of agricultural fertilizers and waste management (Harmens et al., 2008; Ishchenko, 2019).

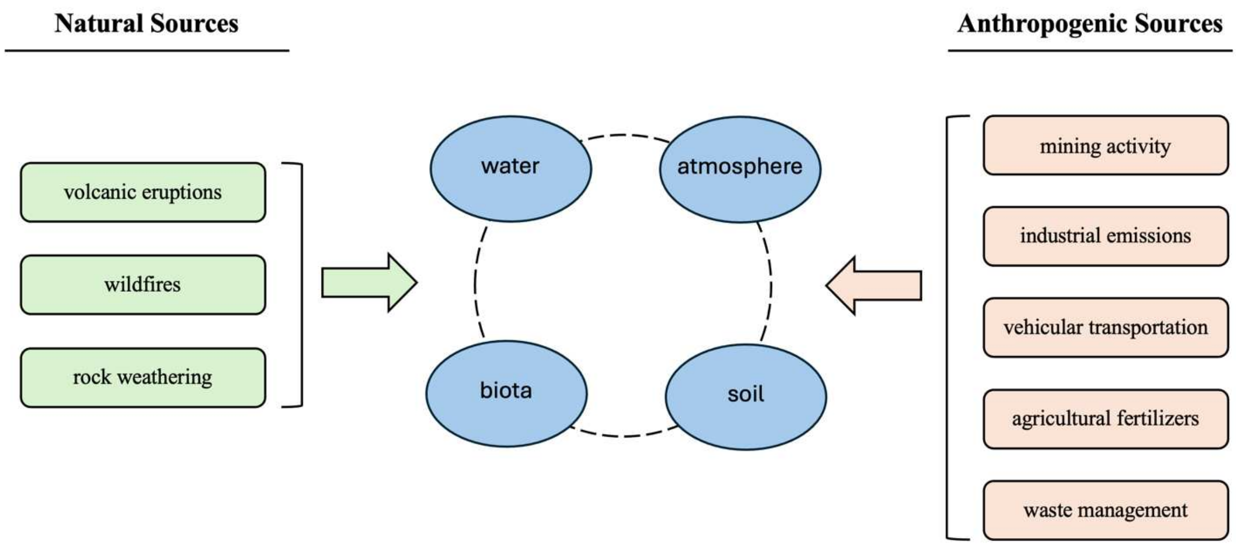


FIGURE 1: MAIN SOURCES OF HEAVY METALS.

Although the term "heavy metal" has been used for decades, it lacks a definitive and universally accepted definition. Often associated with toxicity and density, the term typically refers to elements with a density greater than 4 g/cm^3, including transition metals and metalloids (Duffus, 2002). Given the broad definition, it is clear that not all elements considered as heavy metals exhibit the same chemical behavior or have identical effects on organisms.

Most heavy metals are micronutrients, essential for correct metabolism and growth in plants. They are needed for various metabolic reactions, protein synthesis, enzyme activity, electron transfer, and structural functions. However, when present in high concentrations these elements become toxic for the plant, disrupting normal metabolic processes and causing physiological stress. On the other hand, some heavy metals such as mercury and arsenic, are toxic even in trace amounts. When present, these elements act as stress factor, inducing oxidative damage, disrupting nutrient uptake and other metabolic processes, negatively affecting plant health and development (Nagajyoti, Lee & Sreekanth, 2010).

Plants growing in polluted environments are subjected to significant stress. Even species considered tolerant have reduced fitness under high levels of heavy metals, resulting in slower growth rates and lower biomass compared to individuals of the same species growing in uncontaminated areas (Wilson, 1988; Chibuike & Obiora, 2014). This suggests that, in the presence of high heavy metal concentrations, plants must allocate resources differently to counteract the harmful effects of pollutants (Audet & Charest, 2008). This trend has been observed not only in tracheophyte species but also in bryophytes, such as Ceratodon purpureus (Jules & Shaw, 1994).

CHLOROPHYLL FLUORESCENCE

There are numerous approaches to studying the effects of heavy metal contamination on plants, with one of the most widely used being chlorophyll fluorescence. This technique is employed to assess performance and stress in plants and algae by measuring the photosystem II (PSII) activity and other related parameters. Chlorophyll fluorescence is highly popular due to the commercial availability of affordable, portable measuring instruments and its ability to provide extensive information on plant responses to environmental changes, genetic variation, and ecological diversity (Baker, 2008; Murchie & Lawson, 2013).

This technique relies on our understanding of electron transport during photosynthesis (*Figure 2*). When chlorophyll molecules absorb light, the energy can be utilized in three ways: (1) for photosynthesis (photochemistry), (2) re-emitted as heat or (3) re-emitted as light (fluorescence). These three processes compete with one another, meaning that by measuring chlorophyll fluorescence it is possible to assess the efficiency of photochemistry and the extent of heat dissipation (Murchie & Lawson, 2013).

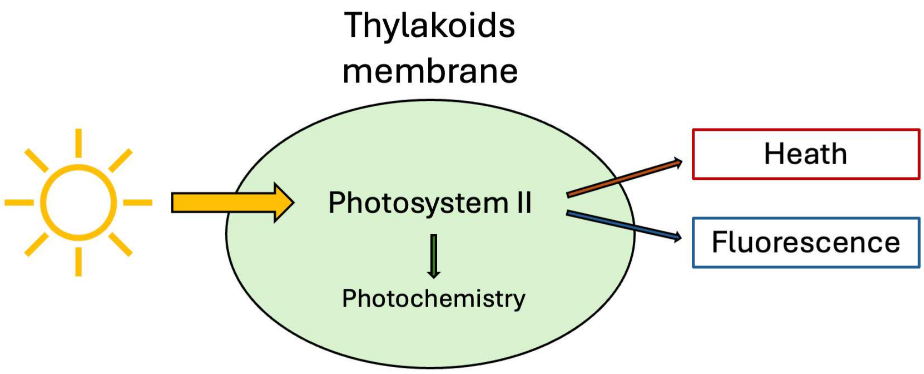


FIGURE 2: POSSIBLE PATHWAYS OF LIGHT ENERGY IN PHOTOSYSTEM II (PSII).

Aims of the Thesis

This work focused on the effects of multiple heavy metals on the bryophytes *Pohlia drummondii* and *Physcomitrium patens* (formerly *Physcomitrella patens*) (*Figure 3*). The choice of species was based on both their availability and their known relationship with heavy metal contamination. *Pohlia drummondii* is a species known for its resistance to different heavy metals (Antreich, Sassmann & Lang, 2016) and has been observed growing in contaminated sites (Adlassnig *et al.*, 2016). On the other hand, while *Physcomitrium patens* has been extensively studied for its role as a model organism (Cove & Knight, 1993), research on its resistance to heavy metal contamination is limited. Experiments on growth in heavy metal enriched media and solutions revealed that *P. patens* can tolerate high levels of contamination (Sassmann *et al.*, 2010). However, there is little information on whether this species grows in polluted sites as *P. drummondii* does.

The original samples come from different locations. Samples of *P. drummondii* were obtained ten years ago from a former copper mining site in Schwarzwand near Salzburg (Austria) (Adlassnig *et al.*, 2013), then propagated and grown on Benecke medium in the following years. The area is characterized by different heavy metals, especially copper and iron, from the mining activity that occurred from 1601 to 1903 (Hackenberg, 2003). The samples of *P. patens* were originally also collected ten years ago, but because of a contamination event that involved all the plants in our laboratory, a new sampling was required. The new culture used for this experiment was kindly provided by the Reski/Rensieng-group from the University of Freiburg (Germany), who also provided the plants ten years ago.

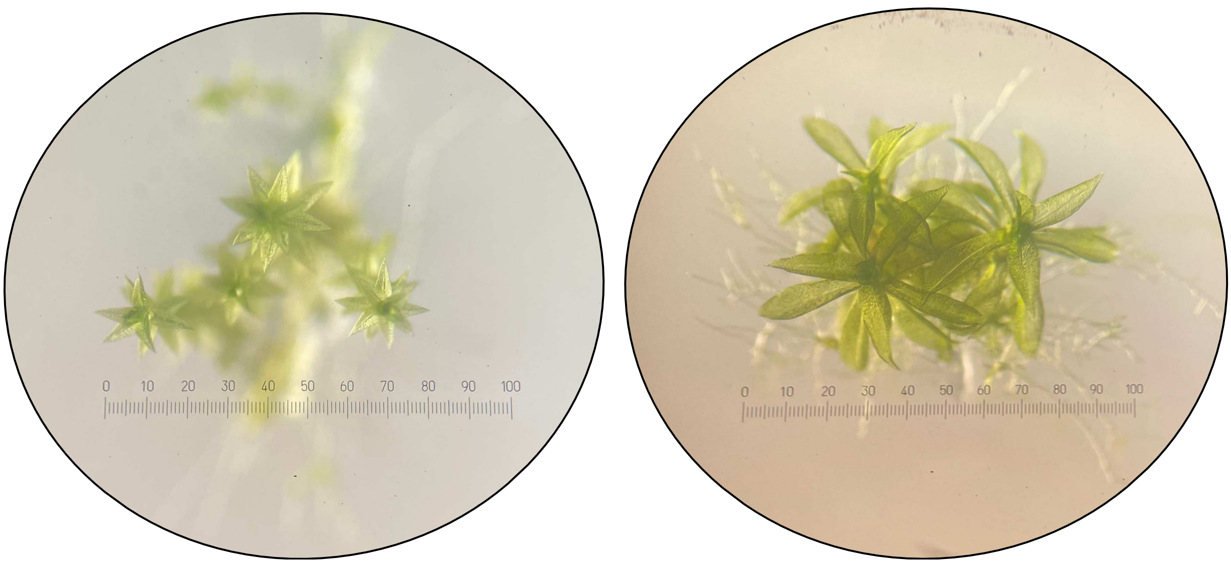


Figure 3: Samples of *Pohlia drummondii* (left) and *Physcomitrium patens* (right) taken at 2.0x with a binocular Reichert microscope.

Both species were exposed to media contaminated with the following heavy metals: copper (Cu), iron (Fe), manganese (Mn), arsenic (As), and antimony (Sb) (Table 3). The first three are important micronutrient which are essential for the correct development and growth of plants, while the last two do not have positive impacts on the plant metabolism. A concentration of 100 μM was used for all contaminants.

Since under natural conditions contamination can occur either as a continuous process (e.g. in contaminated sites) or as a one-time event (e.g. from rainfall or wind deposition), two different treatments were applied. In the first treatment, the plants were grown in contaminated media throughout the entire experiment, to mimic long-term contamination such as the case of mining sites. In the second treatment, the plants were briefly immersed in a contaminated water solution before being transferred to uncontaminated media, to understand the effects of a single contamination event.

This study aims to address the following questions*:*

1) Do the effects of the contamination vary depending on the heavy metal?
2) Do the effects on the plants become more pronounced over time?
3) Is there a difference in how *P.drummondii* and *P.patens* respond to the contamination?
4) Is there a difference between plants growing in a contaminated medium and plants that were only briefly in contact with heavy metals through a short dip in contaminated water solution?

MATERIALS AND METHODS

To ensure sufficient material for the experiment, both species were propagated under a laminar flow hood in petri dishes filled with Benecke medium and sealed with parafilm® to avoid external contamination. All samples were grown in a growth chamber (Conviron ®) maintained at 20°C with a light-dark cycle of 14-10 hours.

MEDIUM PREPARATION

The Benecke medium (Benecke, 1903) was used for both treatments. For 500 mL of medium, 1 µL of micronutrients (*Table 1*) and 5 mL of each of four pre-prepared stock solutions were added to 300 mL of distilled water in a measuring cylinder, then distilled water was added till the desired volume of 500 mL was reached. The stock solutions used were ammonium nitrate (NH_4NO_3), monopotassium phosphate (KH_2PO_4), magnesium sulfate ($MgSO_4$) and calcium chloride ($CaCl_2$) (*Table 2*). All compounds used for the preparation of the stock solutions were purchased from Sigma-Aldrich.

Lastly, 6 g of agar were added and mixed using a magnetic stir bar. During this step, the pH was adjusted to a value of 5.8 ± 0.5 (Yong-Yun *et al.*, 2003) by adding hydrochloric acid, to ensure the optimal growth of the samples. The medium was then autoclaved prior to use.

Chemical	Amount pro 1 L water
H_3BO_3	614 mg
$CuSO_4$ x $5H_2O$	55 mg
$MnCl_2$ x $4H_2O$	389 mg
$CoCl_2$ x $6H_2O$	55 mg
$ZnSO_4$ x $7H_2O$	55 mg
Kl	28 mg
Na_2MoO_4 x $2H_2O$	25 mg

Stock solution	Amount pro 100 mL
NH_4NO_3	2 g
KH_2PO_4	4 g
$MgSO_4$ x $7H_2O$	1 g
$CaCl_2$ x $2H_2O$	1 g

TABLE 1 (LEFT): CHEMICALS FOR 1L OF MICRONUTRIENT.

TABLE 2 (RIGHT): STOCK SOLUTIONS FOR BENECKE MEDIUM PREPARATION, ALONG WITH THEIR RESPECTIVE WEIGHT FOR 100 ML.

Contaminated Medium

In the first treatment, bryophyte fragments were cultivated in petri dishes containing a solid contaminated growth medium. Five dishes were prepared for each species, with each dish contaminated with a different heavy metal. Additionally, a control dish containing only uncontaminated Benecke medium was included to serve as a baseline for comparison.

To prepare the contaminated media, stock solutions for each heavy metal were created by dissolving 0.01 g of the respective chemical compound in 100 mL of distilled water. The compounds used in this experiment, all purchased from Sigma-Aldrich, were copper chloride ($CuCl_2$), iron chloride ($FeCl_3$), manganese chlorite ($MnCl_2$), nitrium arsenate (Na_2HAsO_4), antimony potassium tartrate trihydrate ($K_2Sb_2C_8H_4O_{12}$ x $3H_2O$). For each 100 mL of contaminated medium, a specific volume of the appropriate stock solution was diluted with distilled water (*Table 3*) to achieve a final concentration of 100 μM, following a straightforward dilution calculation. Finally, 1.2 g of agar (Sigma-Aldrich) was added to each preparation while mixing with a magnetic stirrer and the pH was adjusted to 5.8 ± 0.5 to ensure an optimal growth. This specific level of pH was selected after being tested in preliminary experiments and being employed successfully in multiple studies by our research group.

All bottles were then autoclaved and stored at 4 °C. Before use, the media were warmed to a pourable consistency using a microwave, while paying careful attention to prevent overflow caused by boiling. Once poured, the medium was left to cool in the petri dishes for 20 minutes with the lids removed to prevent condensation and to allow the samples to sit properly on the surface. To minimize contamination, this process was conducted under a laminar flow hood following 30 minutes of UV light exposure as a sterilization measure.

In the end, both bryophyte species were propagated by removing small fragments from the original plants growing in uncontaminated petri dishes. These fragments were used to create nine spots in each contaminated dish. The petri dishes were then sealed with parafilm® and placed in the growth chamber set to 20°C.

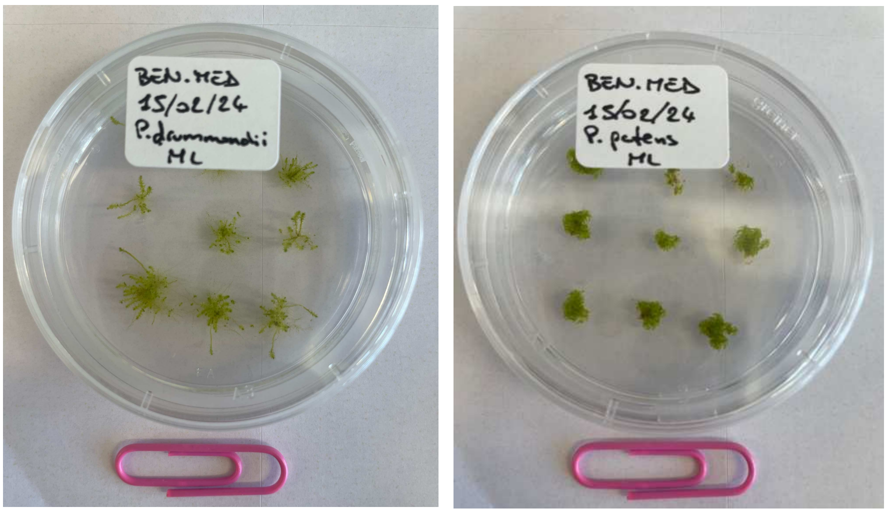


Figure 4: Petri dishes with control samples of *P. drummondii* (left) and *P. patens* (right).

At the time the picture was taken, the samples have been growing for 8 weeks.

CONTAMINATED WATER SOLUTION

The second treatment involved the use of metal contaminated water solutions with a concentration of 100 µM. To achieve this, specific volumes of each metal stock solution were diluted in distilled water (*Table 3*) and subsequently autoclaved. Under the laminar flow hood, the samples were immersed in these contaminated water solutions for 5 seconds before being transferred to petri dishes containing Benecke control medium. Lastly, a control dish was also prepared for both species.

Contaminant	Stock solution	Distilled water
$CuCl_2$	16.949 mL	83.051 mL
$FeCl_3$	27.027 mL	72.973 mL
$MnCl_2$	12.658 mL	87.342 mL
Na_2HAsO_4	31.250 mL	68.750 mL
$K_2Sb_2C_8H_4O_{12}$	62.500 mL	37.500 mL

TABLE 3: AMOUNT OF STOCK SOLUTION AND DISTILLED WATER USED FOR THE PREPARATION OF BOTH CONTAMINATED MEDIA AND DILUTED SOLUTIONS. THESE QUANTITIES AMOUNT TO A FINAL VOLUME OF 100 ML.

PHOTOSYNTHETIC MEASUREMENT

Chlorophyll fluorescence data were collected using an IMAGING-PAM M-Series chlorophyll fluorometer, specifically the MINI version (Measuring Head: IMAG-MIN/B, Camera: IMAG-K). This instrument operates based on the Pulse Amplitude Modulation (PAM) technique, which allows for the measurement of chlorophyll fluorescence even in the presence of environmental light. The fluorometer emits actinic light of variable intensity to drive the photosynthesis in the sample, along with a measuring light consisting of extremely fast pulses (milliseconds) at varying frequencies (Henriques, 2009). Since the detector is sensitive only to the fluorescence triggered by the measuring light, the instrument can differentiate between signals generated by the measuring light and those caused by ambient light, therefore providing accurate data regardless of the light environment (IMAGING-PAM M-Series Chlorophyll Fluorometer - Instrument Description and Information for Users, 2019). The device was connected to a computer and data was recorded using the ImagingWin software.

The experimental growth period lasted for a total of eight weeks for both treatments (contaminated medium and contaminated water solution), with measurements taken every two weeks to allow the bryophytes sufficient time to grow and be affected by the metal contamination. The petri dishes remained sealed during data collection, enabling repeated measurements over the weeks without the risk of external contamination.

Each petri dish was assigned a total of nine spots, corresponding to the nine bryophyte fragments, along with an additional control spot located in an area of the dish free of plant material, acting as a control measurement. This was done to ensure that the surface on which the dishes were placed did not interfere with the measurements. The instrument recorded a series of parameters for each spot, with the parameters used in this study summarized in *Table 4*. Each spot produced 14 values for all parameters, corresponding to different levels of Photosynthetically Active Radiation (PAR), ranging from 0 to 1467 μmol quanta $m^{-2} s^{-1}$. These values reflect measurements taken under varying light intensities generated by the instrument. The selection of PAR values was based on the expertise of researchers familiar with the instrument and its pre-existing settings.

Since the experiment did not focus on exploring changes in chlorophyll fluorescence between dark and light conditions, only the parameters referring to light-adapted leaves were considered for the statistical analysis.

Parameter	Formula	Definition
Fo'		Minimal fluorescence for light adapted leaves
Fm'		Maximal fluorescence for light adapted leaves
Fv'	Fm'- Fo'	Variable fluorescence for light adapted leaves
Fv'/Fm'	(Fm'- Fo')/ Fm'	PSII maximum efficiency

TABLE 4: LIST OF PARAMETERS CONSIDERED FOR THE ANALYSIS, WITH DEFINITIONS TAKEN FROM BAKER (2008).

Statistical Analysis

The data obtained with the IMAGING-PAM chlorophyll fluorometer required cleaning before analysis. In two petri dishes, *P.drummondii*-medium-copper and *P.patens*-dipping-arsenic, only eight spots were measurable due to the lack of growth in the ninth spot, which was consequently excluded. Additionally, in the case of *P.drummondii*-medium-copper, the spots could not be measured at eight weeks because the samples were no longer visible, likely due to the severe negative effects of the copper contamination. In this instance, a value of zero was assigned to these measurements, as the overall activity in the entire area of the petri dish was equal to that of the control spot.

The data analysis was conducted using the statistical language R in RStudio. The primary parameter analyzed was Fv'/Fm', calculated from the Fo' and Fm' data (*Table 4*). Because of the non-normal distribution of the data, the non-parametric Kruskal-Wallis test was employed. Although this test does not account for the repeated measurements taken over the eight weeks, it was considered the most appropriate statistical approach. This decision was based on the fact that the measurements were taken randomly each time, without adhering to a specific order for the spots, making the Friedman test unsuitable for this analysis. The Dunn's test was employed as a post-hoc analysis following the Kruskal-Wallis test, with the significant level set at $\alpha = 0.01$. This stricter threshold was chosen because the test revealed numerous significant differences and using a lower α than the standard 0.05 improves the robustness of the results by reducing the likelihood of Type I errors.

The mean values of Fv'/Fm' were calculated and plotted for better visualization. Standard deviations were also computed to show the variability of each measurement. However, they are provided in the supplementary material instead of being included in the graphs to prevent excessive clutter that could reduce readability.

The normal trend for Fv'/Fm' curves shows high values at low PAR followed by a decrease with the increase of PAR, until it reaches a steady level. This pattern can be explained by looking at the molecular reactions taking place during the photosynthetic process. Light stimulates the light-harvesting complexes (LHCs) of both PSI and PSII, resulting in most of the absorbed light being used for photosynthesis with minimal energy loss as heat. However, with the increase in solar radiation over time, the PSII system becomes saturated, leading to energy accumulation that poses a risk to the system's structure. To avoid damage, the plant increases heat dissipation, resulting in lower values of Fv'/Fm'. Eventually, both the photosynthesis process and heat dissipation reach an equilibrium, causing the Fv'/Fm' curve to stabilize at a lower value than its initial one. By looking at the trend of the Fv'/Fm' curves, it is possible to understand whether the different contaminated conditions used in this experiment pose a strain on the plant species, acting thus as a stress factor.

RESULTS

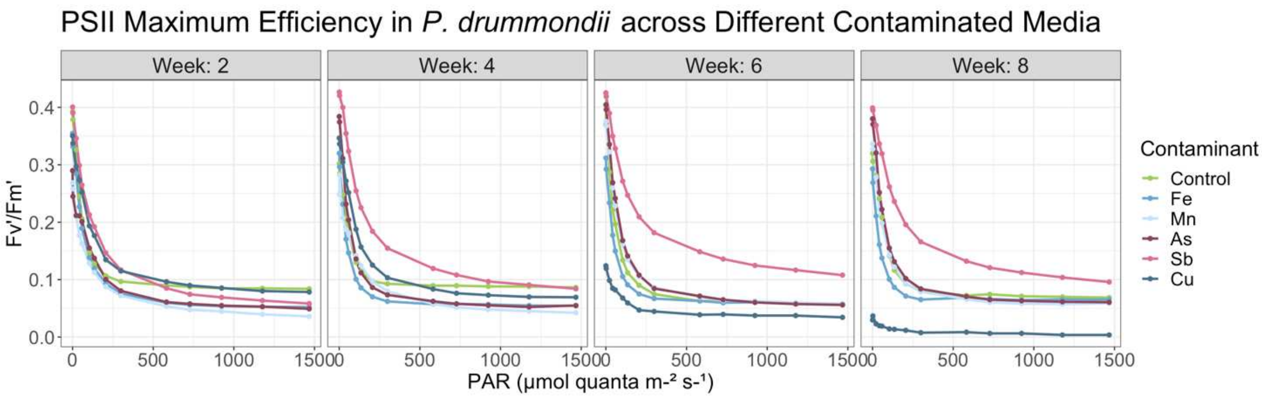
COMPARISON BETWEEN CONTAMINANTS

For each species and treatment, contaminants were compared across all eight weeks, revealing numerous strong statistically significant differences (*Table 5*). In *P. drummondii*, the medium treatment exhibited more significant differences than the contaminated water solution treatment, with most differences occurring in Week 2. In contrast, *P. patens* showed several statistically significant differences in both treatments, slightly more numerous for the contaminated medium treatment than for the contaminated water solution treatment.

Pohlia drummondii – Contaminated Media

For the contaminated medium treatment, the different physiological reactions caused by heavy metals contamination had a similar shape at the first measurement, with the only differences being the starting value of Fv'/Fm' and the level of stabilization of the curve (*Graph 1*). In the following weeks, Cu and Sb provoked the most noticeable reactions from the plants, with these curves assuming distinct trends. From Week 4 in the case of Sb and Week 6 for Cu, the curves for these two heavy metals diverged from the control and the others ($p < 0.001$). In the case of Sb, the Fv'/Fm' values across PAR increased compared to the control, resulting in higher curves and a less pronounced slope. The distance between the Sb curve and the others kept increasing over time until there was no longer any crossing point between one another. In contrast, Cu contamination caused the opposite trend, where plant response began to decline from Week 6, reaching a minimum at Week 8 with a starting value of 0.03 and the curve settling close to zero.

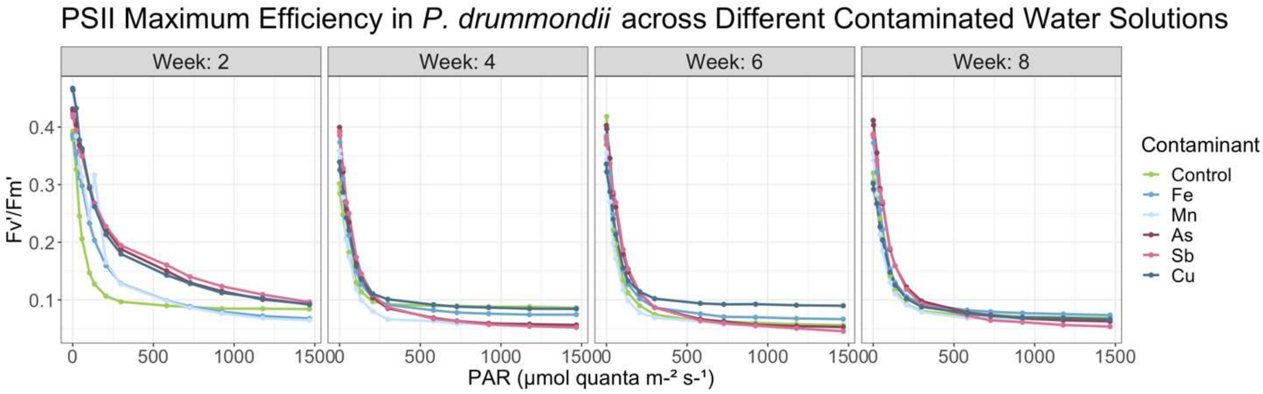
The responses to the other three contaminants (As, Fe, Mn) remained very close to the control treatment from the beginning (*Graph 1*). Over time, these similarities increased to the point where all curves were almost overlapping in the last measurement. The statistical analysis not only confirmed the lack of significant differences between the control and the contaminants, but also between the contaminants themselves, with very few exceptions (*Table 5*).



GRAPH 1: VALUES OF PSII MAXIMUM EFFICIENCY FOR SAMPLES OF *POHLIA DRUMMONDII* ILLUSTRATING THE EFFECTS OF DIFFERENT CONTAMINATED MEDIA OVER AN EIGHT-WEEK PERIOD.

Pohlia drummondii – Contaminated Water Solutions

There were fewer statistically significant differences between contaminants in the contaminated water solution treatment compared to the contaminated medium treatment. Most of these differences were observed at Week 2. Looking at *Graph 2*, it is easy to appreciate how the shapes of the curves representing the plant response to different heavy metal contaminations had less steep slopes than the curve of the control treatment. These curves clustered into two groups. The first, consisting of As, Cu and Sb, was characterized by higher Fv'/Fm' values and a final value close to that of the control treatment, but with no previous intersection. The second group, which included Fe and Mn, showed lower Fv'/Fm' values than the curves from the other group, with the final value being lower than that of the control. In the following weeks, all curves changed their shape to resemble the control curve, with very few significant differences revealed by the statistical analysis (*Table 5*).



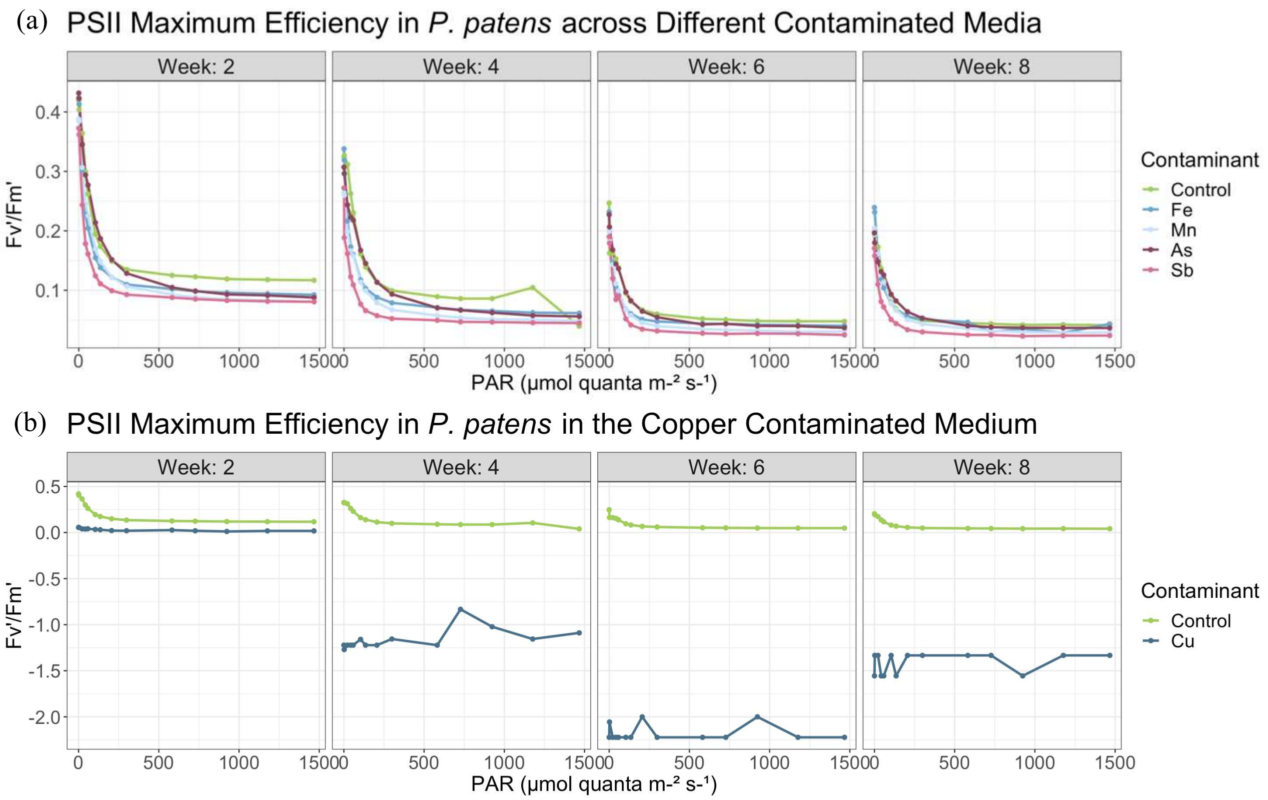
GRAPH 2: VALUES OF PSII MAXIMUM EFFICIENCY FOR SAMPLES OF *POHLIA DRUMMONDII* ILLUSTRATING THE EFFECTS OF DIFFERENT CONTAMINATED WATER SOLUTIONS OVER AN EIGHT-WEEK PERIOD.

Physcomitrium patens – Contaminated Media

Looking at the contaminated medium treatment results (*Graph 3a*), although the curves of the contaminants maintained a similar shape to the control, the settling Fv'/Fm' value was lower than the control for all curves. This trend persisted across all four measurements, with all curves including the control showing progressively lower Fv'/Fm' values and starting value over time. Among all contaminants, As results were the most similar to the control, while Sb showed the most significant differences across all four measurements ($p < 0.001$). Similar to *P. drummondii*, in *P. patens* the Fv'/Fm' curves for As, Fe and Mn were very similar to each other, with statistically significant differences occurring only between As and Mn at Week 4 and Week 6. However, unlike *P. drummondii,* the results for Sb were not significantly different from those for Mn, while remaining statistically significantly different from As and Fe (*Table 5*).

The results for copper (*Graph 3b*), require brief clarification and should be interpreted with caution. Among all petri dishes, these were the only ones where plants exhibited visible damage, with shoots appearing brown and deteriorated already from the first measurement. Throughout the experiment, the fluorometer detected very low activity, apart from the last measurement, where only one of the nine plants expressed some activity. Since the final parameter considered in the results is derived by subtracting two fluorometer parameters, the curve at Week 8 is higher than the one at Week 6. However, this is merely a mathematical outcome and does not indicate an actual increase in PSII maximum efficiency. This also explains why the Fv'/Fm' curves do not follow the usual curved shape, except for the first measurement.

Even though the results from Cu contamination were not reliable enough to describe a specific trend since most of the samples died during the eight-weeks of the experiment, it was still possible to gather some observations. Comparing to the control curve, the response to Cu was lower as early as Week 2, with the settling value being extremely close to zero (*Graph 3b*). The same was true for the starting value of Fv'/Fm', with a value of 0.05 compared to the 0.4 of the control.

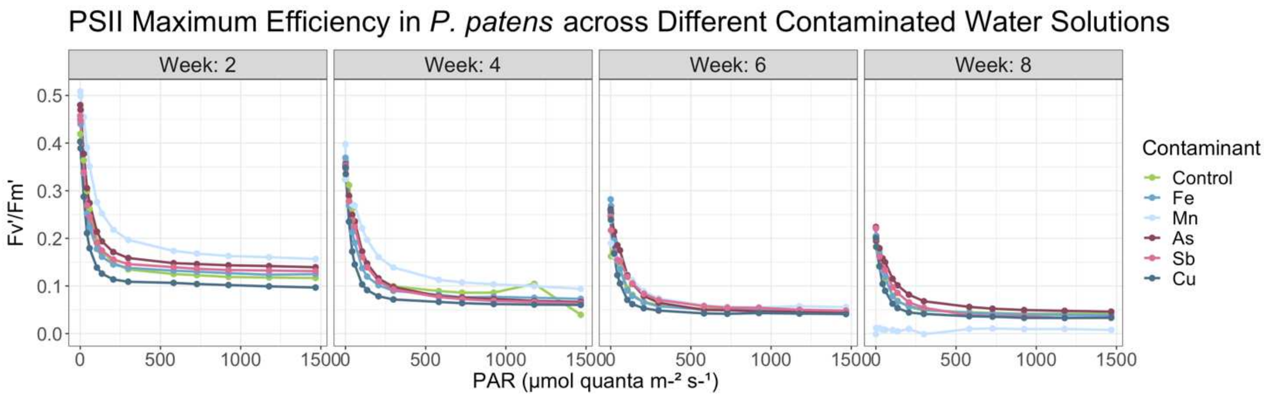


Graph 3: Values of PSII maximum efficiency for samples of *Physcomitrium patens* illustrating the effects of different contaminated media over an eight-week period. The results from Cu are illustrated separately in (b) because of the different scale required to appreciate the trends.

Physcomitrium patens – Contaminated Water Solutions

In the contaminated water solution treatment, most of the significant differences were observed at Week 2 (*Graph 4*), as was the case for *P. drummondii*. With the exception of the Cu curve, all others showed higher Fv'/Fm' values than the control at Week 2, with Mn being the highest among them. The shape of the curves remained consistent across all heavy metal contaminations and in the subsequent measurements, only with a progressive lowering of the starting value with time. In the following weeks, all curves converged towards the control one, with Cu remaining overall the lowest in Fv'/Fm' values. However, results for Mn were particularly unusual at Week 8, where the previous trend of its curves became almost linear with no slope and values approaching zero.

Overall, the statistical analysis confirmed the observations from the graphs of results from As, Fe and Sb being very similar to the control and to each other, with only a few exceptions (*Table 5*). On the other hand, results for Cu and Mn were significantly different from one another and from the control treatment, specifically at Week 2 and Week 8.



GRAPH 4: VALUES OF PSII MAXIMUM EFFICIENCY FOR SAMPLES OF *PHYSCOMITRIUM PATENS* ILLUSTRATING THE EFFECTS OF DIFFERENT CONTAMINATED WATER SOLUTIONS OVER AN EIGHT-WEEK PERIOD.

			Pohlia drummondii		*Physcomitrium patens*	
Week	Contaminant 1	Contaminant 2	Medium	Dipping	Medium	Dipping
2	As	Control	1.063e-03 **	2.501e-07 ***	0.055	3.406e-03 **
	As	Cu	1.195e-03 **	0.400	8.469e-37 ***	2.176e-10 ***
	Control	Cu	0.477	6.503e-08 ***	3.620e-46 ***	1.344e-04 ***
	As	Fe	0.426	6.017e-04 ***	0.094	5.387e-03 **
	Control	Fe	1.952e-03 **	0.037	1.790e-03 **	0.436
	Cu	Fe	2.145e-03 **	2.409e-04 ***	6.306e-30 ***	7.105e-05 ***
	As	Mn	0.078	5.436e-03 **	0.033	1.851e-03 **
	Control	Mn	3.538e-06 ***	6.580e-03 **	2.976e-04 ***	3.711e-09 ***
	Cu	Mn	5.081e-06 ***	2.560e-03 **	2.079e-27 ***	2.154e-21 ***
	Fe	Mn	0.054	0.245	0.301	9.530e-09 ***
	As	Sb	1.889e-04 ***	0.451	6.505e-05 ***	0.059
	Control	Sb	0.315	1.314e-07 ***	2.892e-08 ***	0.120
	Cu	Sb	0.340	0.448	7.404e-19 ***	7.240e-07 ***
	Fe	Sb	3.775e-04 ***	3.894e-04 ***	5.996e-03 **	0.155
	Mn	Sb	3.273e-07 ***	3.804e-03 **	0.023	2.047e-06 ***
4	As	Control	0.038	0.196	0.021	0.140
	As	Cu	0.028	0.028	2.985e-51 ***	4.245e-04 ***
	Control	Cu	0.425	0.144	1.630e-65 ***	2.622e-06 ***
	As	Fe	0.033	0.114	0.158	0.235
	Control	Fe	1.488e-04 ***	0.363	1.178e-03 **	0.031
	Cu	Fe	1.081e-04 ***	0.238	6.501e-45 ***	3.533e-03 **
	As	Mn	0.061	0.022	5.381e-03 **	5.315e-03 **
	Control	Mn	4.456e-04 ***	2.036e-03 **	2.209e-06 ***	0.065
	Cu	Mn	3.206e-04 ***	4.144e-05 ***	5.910e-36 ***	6.309e-10 ***
	Fe	Mn	0.384	6.353e-04 ***	0.061	3.644e-04 ***
	As	Sb	1.298e-09 ***	0.446	7.256e-07 ***	0.292
	Control	Sb	1.444e-05 ***	0.236	3.486e-12 ***	0.046
	Cu	Sb	5.501e-05 ***	0.037	1.034e-24 ***	2.031e-03 **
	Fe	Sb	3.105e-15 ***	0.142	6.754e-05 ***	0.429
	Mn	Sb	3.072e-14 ***	0.016	0.012	6.897e-04 ***
6	As	Control	0.121	0.090	0.147	0.142
	As	Cu	3.126e-15 ***	0.052	1.308e-52 ***	4.840e-04 ***
	Control	Cu	1.328e-11 ***	1.509e-03 **	8.440e-60 ***	0.011
	As	Fe	6.815e-03 **	0.330	0.127	0.107
	Control	Fe	0.097	0.037	0.014	0.430

			Pohlia drummondii		*Physcomitrium patens*	
Week	Contaminant 1	Contaminant 2	Medium	Dipping	Medium	Dipping
6	Cu	Fe	3.231e-08 ***	0.118	2.601e-45 ***	0.017
	As	Mn	0.425	9.717e-03 **	3.498e-03 **	0.257
	Control	Mn	0.164	0.160	9.039e-05 ***	0.334
	Cu	Mn	1.320e-14 ***	3.727e-05 ***	2.805e-36 ***	3.176e-03 **
	Fe	Mn	0.011	2.737e-03 **	0.060	0.272
	As	Sb	2.580e-08 ***	0.378	2.303e-06 ***	0.349
	Control	Sb	1.860e-11 ***	0.151	9.042e-09 ***	0.067
	Cu	Sb	2.090e-39 ***	0.026	9.943e-27 ***	7.206e-05 ***
	Fe	Sb	1.261e-15 ***	0.226	2.908e-04 ***	0.047
	Mn	Sb	8.739e-09 ***	0.021	0.030	0.142
8	As	Control	0.474	0.043	0.309	0.027
	As	Cu	2.787e-31 ***	0.046	1.670e-49 ***	3.466e-06 ***
	Control	Cu	5.805e-31 ***	0.487	9.070e-53 ***	4.092e-03 **
	As	Fe	0.032	0.486	0.445	6.180e-03 **
	Control	Fe	0.037	0.046	0.359	0.278
	Cu	Fe	6.791e-23 ***	0.050	2.098e-50 ***	0.020
	As	Mn	0.298	0.011	0.103	8.772e-44 ***
	Control	Mn	0.321	0.280	0.039	7.181e-35 ***
	Cu	Mn	9.882e-29 ***	0.269	9.975e-42 ***	3.346e-22 ***
	Fe	Mn	0.094	0.012	0.080	8.683e-32 ***
	As	Sb	1.160e-07 ***	0.197	6.511e-06 ***	6.671e-03 **
	Control	Sb	8.174e-08 ***	0.195	5.900e-07 ***	0.287
	Cu	Sb	4.024e-62 ***	0.204	1.455e-25 ***	0.019
	Fe	Sb	1.110e-12 ***	0.206	3.411e-06 ***	0.489
	Mn	Sb	5.909e-09 ***	0.074	9.763e-04 ***	6.240e-32 ***

TABLE 5: SIGNIFICANCE LEVELS BETWEEN CONTAMINANTS FOR EACH WEEK AND TREATMENT IN *POHLIA DRUMMONDII* AND *PHYSCOMITRIUM PATENS*. $\alpha = 0.01$, " ** " P_VALUE < 0.01, " *** " P_VALUE < 0.001

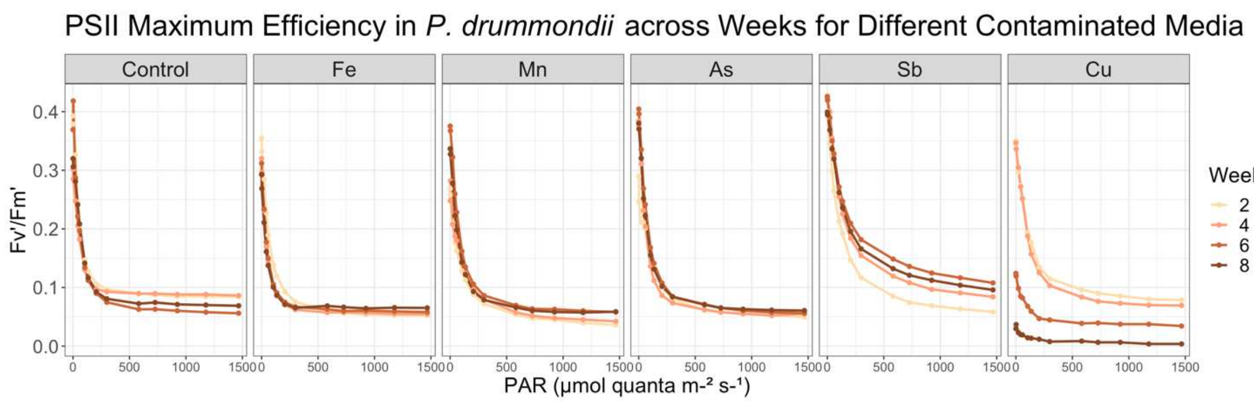
COMPARISON BETWEEN WEEKS

Pohlia drummondii

Graph 5 highlights the differences between the four measurements for the control and each contaminant in the contaminated medium treatment. In the control, results from the first two measurements overlapped, followed by a decrease in Fv'/Fm' values in the following measurements. However, there was no direct correlation between time and decrease in Fv'/Fm', as the values at Week 8 were higher than those at Week 6 and the statistical analysis did not reveal any significant differences between the first and last two measurements (*Table 6*). The same trend observed in the control was also seen for Mn contamination, while in the case of As and Fe, the curves overlapped to the point that no significant differences could be found among any measurements.

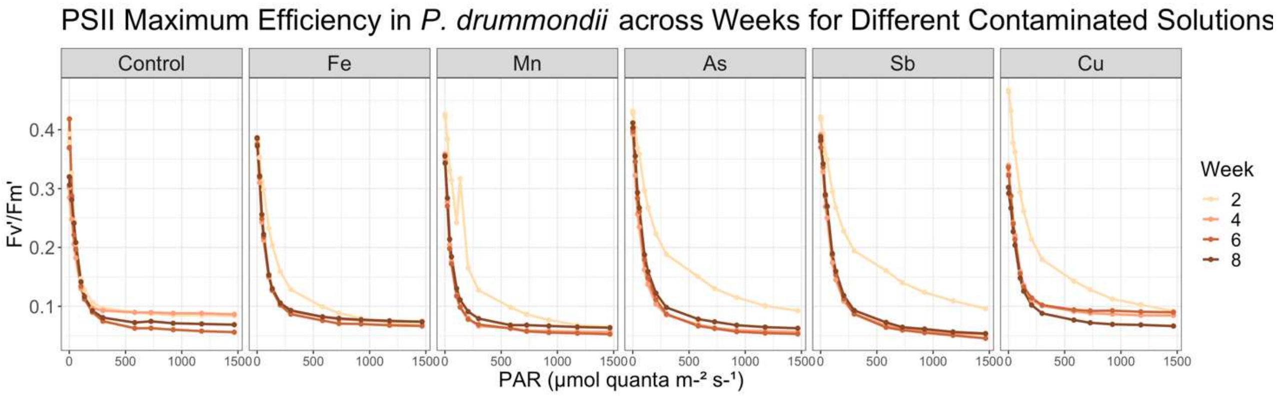
The most interesting results came from the Sb and Cu contaminations. In the case of Sb, the trend was opposite to that of the other heavy metals, with Fv'/Fm' values increasing over time instead of decreasing, even though the only significant differences were between Week 2 and the following weeks. For Cu results, the trend showed a decrease in Fv'/Fm' values in time, with all differences between the first two measurements and the later ones being statistically significant ($p < 0.001$). Another particularity for Cu contamination was the dramatic decrease in the Fv'/Fm' starting value at 0 PAR after Week 4, a pattern not shared by either the control treatment or the other heavy metal contaminations.

The significant differences in the contaminated water solution treatment were overall more numerous (*Table 6*). For most of the contaminants (As, Cu, Mn, Sb), the plant responses were characterized by higher Fv'/Fm' values during the first measurement at Week 2, followed by a sharp decrease that persisted across all three following measurements (*Graph 5b*). For all these contaminants, the differences between Week 2 and the next weeks were the only significant ones, supporting the information shown in the graphical representation ($p < 0.001$). For all these contaminations, the starting value of Fv'/Fm' was higher in the first measurement, only to decline over time. Overall, a similar trend was shared by Fe results, though differences between the Week 2 curve and the others were weaker and there was a small increase in the starting value over time, as opposed to the other contaminants.



GRAPH 5: VALUES OF PSII MAXIMUM EFFICIENCY FOR SAMPLES OF *POHLIA DRUMMONDII* ILLUSTRATING THE DIFFERENCES ACROSS EIGHT WEEKS FOR ALL CONTAMINANTS IN THE CONTAMINATED MEDIUM TREATMENT.

The significant differences in the contaminated water solution treatment were overall more numerous (*Table 6*). For most of the contaminants (As, Cu, Mn, Sb), the plant responses were characterized by higher Fv'/Fm' values during the first measurement at Week 2, followed by a sharp decrease that persisted across all three following measurements (*Graph 5b*). For all these contaminants, the differences between Week 2 and the next weeks were the only significant ones, supporting the information shown in the graphical representation ($p < 0.001$). For all these contaminations, the starting value of Fv'/Fm' was higher in the first measurement, only to decline over time. Overall, a similar trend was shared by Fe results, though differences between the Week 2 curve and the others were weaker and there was a small increase in the starting value over time, as opposed to the other contaminants.

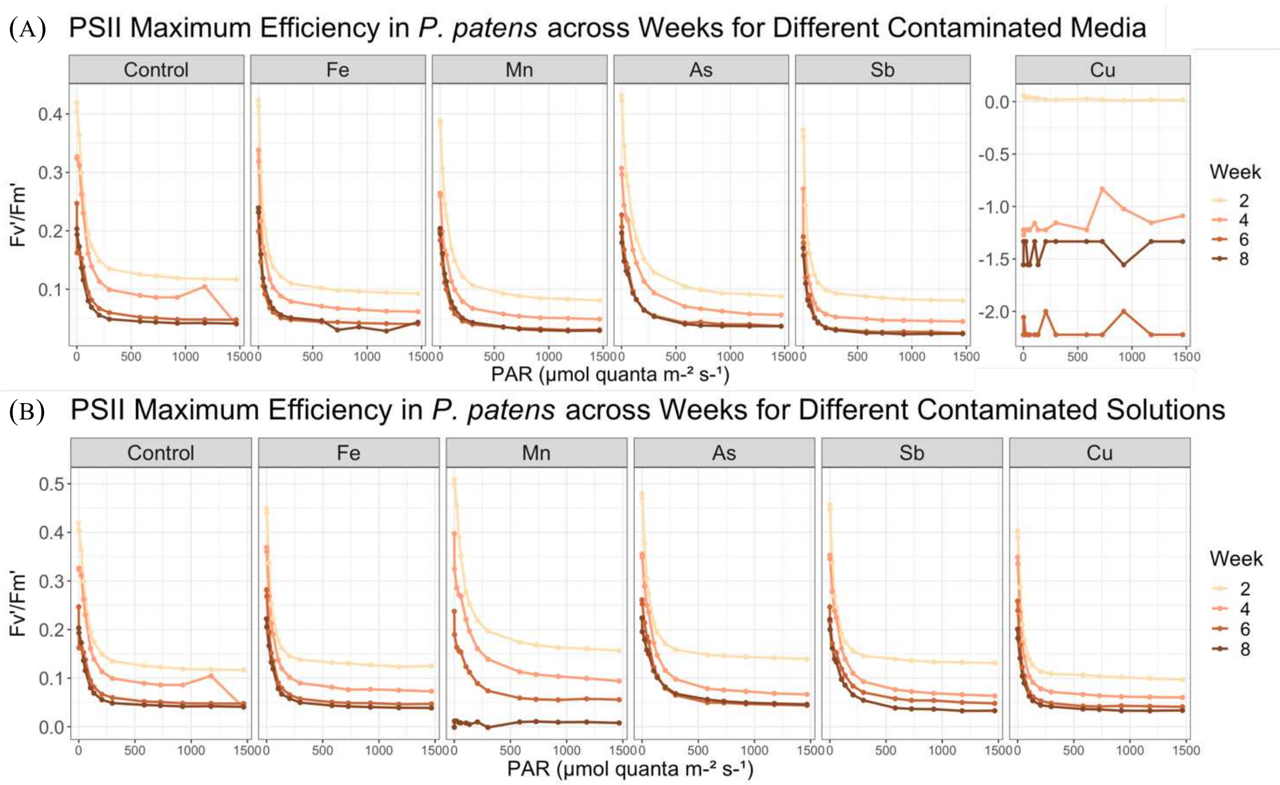


GRAPH 6: VALUES OF PSII MAXIMUM EFFICIENCY FOR SAMPLES OF *POHLIA DRUMMONDII* ILLUSTRATING THE DIFFERENCES ACROSS EIGHT WEEKS FOR ALL CONTAMINANTS IN THE CONTAMINATED WATER SOLUTION TREATMENT.

Physcomitrium patens

In *P. patens*, most of the comparisons between weeks were statistically significant for all contaminants in the contaminated medium treatment (*Table 6*). Except for Cu, the plant response to all heavy metals followed a similar trend, which was also observed in the control treatment (*Graph 7*). Overall, a decrease in Fv'/Fm' values was observed over time, with only results from Week 6 and Week 8 overlapping showing no significant difference. The drop in the Fv'/Fm' starting value, corresponding to 0 PAR, was particularly noticeable for all contaminations as well as the control, for which it decreased from a value of 0.42 to 0.20 over the eight weeks of the experiment. Unfortunately, there was little to be deducted from the Cu plant response, as most of the samples died after the first measurement.

Results from the contaminated water solution treatment showed a similar trend to that of the contaminated medium treatment. The response to As, Cu, Fe and Sb exhibited a decrease in Fv'/Fm' values over time, resulting in lower curves and starting values (*Graph 8*). In these cases, as for the control treatment, all differences between weeks were statistically significant ($p < 0.001$), with the single exception of the last two measurements, which often overlapped. A particular trend was observed for Mn. While the first three measurements shared the same pattern as the other contaminants and the control treatment, with a decrease in Fv'/Fm' values and starting values over time, the results for Week 8 were significantly different from those at Week 6. The classical shape was also lost, with the slope flattening and the values settling close to zero for all PAR measurements.



GRAPH 7: VALUES OF PSII MAXIMUM EFFICIENCY FOR SAMPLES OF *PHYSCOMITRIUM PATENS* ILLUSTRATING THE DIFFERENCES ACROSS EIGHT WEEKS FOR ALL CONTAMINANTS IN THE (A) CONTAMINATED MEDIUM TREATMENT AND (B) CONTAMINATED WATER SOLUTION.

			Pohlia drummondii		*Physcomitrium patens*	
Contaminant	Week 1	Week 2	Medium	Dipping	Medium	Dipping
Control	2	4	0.166		9.597e-04 ***	
	2	6	4.390e-04 ***		6.141e-20 ***	
	4	6	9.245e-03 **		1.230e-09 ***	
	2	8	0.015		5.800e-26 ***	
	4	8	0.113		8.551e-14 ***	
	6	8	0.126		0.08	
Fe	2	4	0.067	0.019	4.330e-05 ***	1.078e-04 ***
	2	6	0.191	2.743e-03 **	3.473e-21 ***	3.584e-16 ***
	4	6	0.265	0.245	2.530e-08 ***	6.280e-06 ***
	2	8	0.23	0.044	5.639e-18 ***	3.087e-23 ***
	4	8	0.223	0.353	1.787e-06 ***	3.625e-10 ***
	6	8	0.447	0.143	0.208	0.036
Mn	2	4	0.345	6.401e-08 ***	4.941e-06 ***	3.642e-05 ***
	2	6	1.753e-03 **	1.697e-08 ***	4.068e-20 ***	7.330e-20 ***
	4	6	5.853e-03 **	0.406	1.355e-06 ***	1.883e-07 ***
	2	8	0.02	6.659e-05 ***	1.546e-17 ***	6.877e-70 ***
	4	8	0.048	0.072	2.869e-05 ***	8.085e-43 ***
	6	8	0.195	0.045	0.252	4.514e-18 ***
As	2	4	0.285	7.594e-09 ***	2.808e-04 ***	4.968e-06 ***
	2	6	0.027	2.662e-08 ***	2.919e-17 ***	1.254e-16 ***
	4	6	0.087	0.413	4.352e-07 ***	7.958e-05 ***
	2	8	0.043	1.183e-05 ***	1.380e-20 ***	1.503e-19 ***
	4	8	0.126	0.076	3.772e-09 ***	2.684e-06 ***
	6	8	0.415	0.113	0.195	0.22
Sb	2	4	2.350e-03 **	1.610e-08 ***	9.287e-08 ***	6.121e-06 ***
	2	6	1.053e-05 ***	8.027e-09 ***	6.351e-22 ***	2.219e-16 ***
	4	6	0.077	0.452	7.153e-06 ***	8.745e-05 ***
	2	8	1.056e-03 **	3.665e-07 ***	3.502e-26 ***	5.864e-25 ***
	4	8	0.402	0.282	5.581e-08 ***	2.081e-09 ***
	6	8	0.119	0.243	0.167	0.017
Cu	2	4	0.283	5.003e-08 ***	2.712e-27 ***	3.048e-05 ***
	2	6	6.321e-11 ***	5.160e-08 ***	7.040e-79 ***	1.189e-16 ***
	4	6	2.340e-09 ***	0.498	5.793e-16 ***	1.381e-05 ***
	2	8	8.886e-35 ***	1.174e-13 ***	1.150e-38 ***	4.814e-25 ***
	4	8	8.842e-32 ***	0.023	0.014	1.914e-10 ***
	6	8	3.050e-09 ***	0.022	3.027e-09 ***	0.019

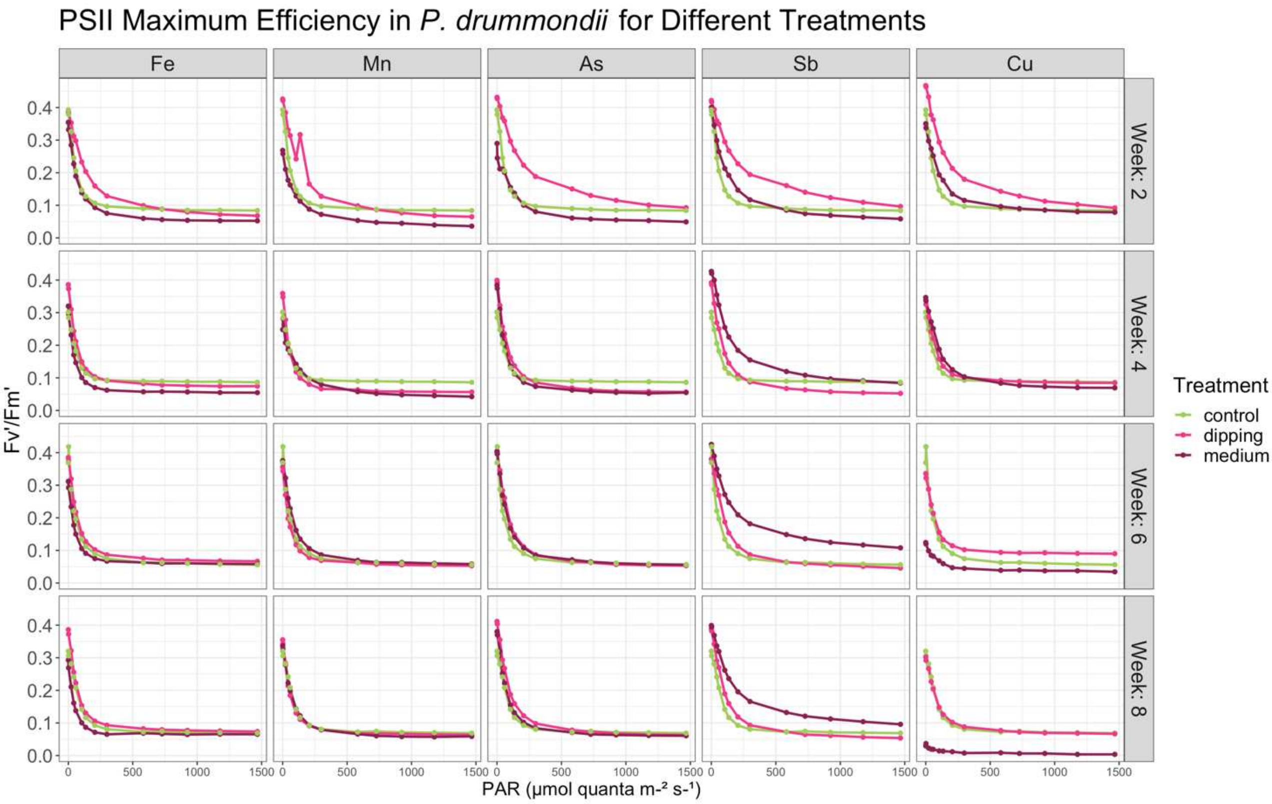
TABLE 6: SIGNIFICANCE LEVELS BETWEEN WEEKS FOR EACH CONTAMINANT AND TREATMENT IN *POHLIA DRUMMONDII* AND *PHYSCOMITRIUM PATENS*. $\alpha = 0.01$, " ** " P_VALUE < 0.01, " *** " P_VALUE < 0.001.

Comparison Between Treatments

Pohlia drummondii

Results from both treatments and the control for *P. drummondii* are visible in *Graph 9*. Comparing the contaminated medium and the contaminated water solution treatments, most of the differences were observable in the first measurement at Week 2. At this time point, results from all contaminations indicated a statistically significant difference between the two treatments (*Table 7*), with Fv'/Fm' values for the dipping curve always being higher than the corresponding medium curve. In the following weeks, the plants' response diverged into two different trends. In the first one, including Cu, Fe and Sb, the differences between treatments persisted over time, with the dipping curve remaining higher than the medium for Fe and Cu while rising above it as soon as Week 4 for Sb. The second trend applied to As and Mn, where the differences between the two treatments were significant only at Week 2. In the following weeks, the results were so similar that the corresponding curves overlapped in the graph.

The two treatments were also compared to the control treatment. Overall, the contaminated water solution treatment was closer to the control than the contaminated medium treatment, with few significant differences observed in the first two measurements (*Table 7*). In the contaminated medium treatment, the reactions to the employed heavy metals could be divided into two groups. For As, Fe and Mn, significant differences between the medium and control curves were limited to the first two measurements, with Fv'/Fm' values for the medium



Graph 8: Values of PSII maximum efficiency for samples of *Pohlia drummondii*. The graph illustrates the differences between the control and the two treatments for each contaminant and week.

being lower than those of the control. On the other hand, for Cu and Sb contaminations, the differences were significant in the later measurements, respectively from Week 6 and Week 4. However, their trends for the Fv'/Fm' values differed: for Cu, the medium curves were lower compared to the control, whereas higher in Sb.

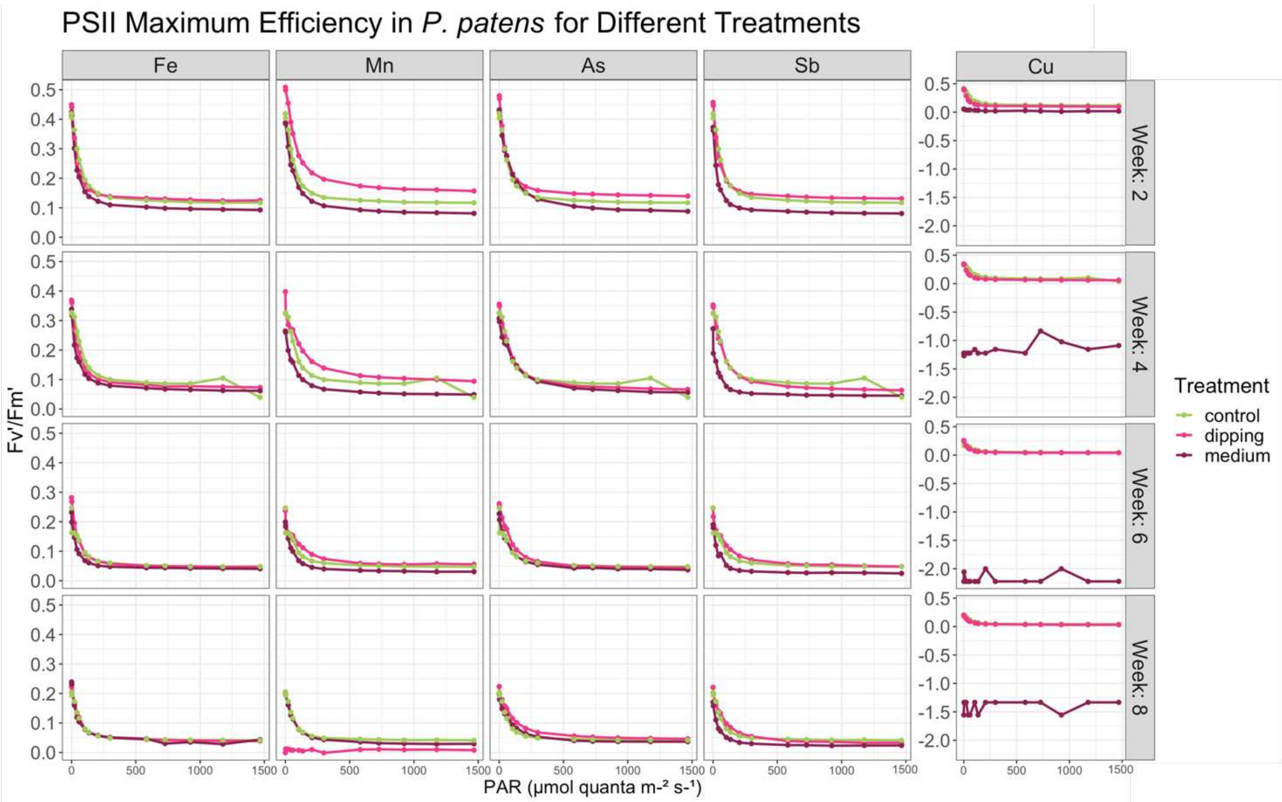
Physcomitrium patens

In the case of *P. patens*, the comparison between treatments revealed that the plants' responses to both were significantly different for all contaminants across all weeks, with only a few exceptions for Fe and Mn (*Table 7*). In *Graph 9*, which illustrates these results, these differences are evident for some heavy metals such as Mn and Sb, and at certain time points, like in the case of Week 2. However, some differences, although present, are more difficult to discern through graphical representation alone. Despite this, there is an overall trend of the Fv'/Fm' values from the contaminated water solution treatment being higher than those from the contaminated medium treatment, a pattern also observed in *P. drummondii*. The only exception was for Mn results at Week 8, where the characteristic curve shape was lost and values settled near zero. Lastly, in all cases where the differences between the two treatments were significant, the starting value for the Fv'/Fm' curves was higher in the contaminated water solution treatment compared to the contaminated medium treatment.

The differences between treatments for Cu contamination were extremely pronounced. However, it is important to remember that these results were influenced by the death of most of the samples after Week 2, resulting in the lines from Week 4 onwards being unreliable.

Comparing each treatment to the control, the contaminated water solution treatment showed greater similarities, resulting in many overlapping curves. Statistically significant differences between the two were observed only for As and Mn at Week 2 and Week 8, as well as for Cu in the first two measurements (*Table 7*). On the other hand, not a singular significant difference between the contaminated water solutions and the control treatments was found for Fe and Sb contaminations, further confirmed by the almost perfect overlap of these curves.

The curves representing the contaminated medium treatments tended to diverge from the control curves, as confirmed by the numerous statistically significant differences found in the analysis (*Table 7*). The rare exceptions occurred only in the later measurements, with only differences in Sb remaining constantly significant over time. These conclusions exclude the results for Cu due to the reasons mentioned earlier.



GRAPH 9: VALUES OF PSII MAXIMUM EFFICIENCY FOR SAMPLES OF *PHYSCOMITRIUM PATENS*. THE GRAPH ILLUSTRATES THE DIFFERENCES BETWEEN THE CONTROL AND THE TWO TREATMENTS FOR EACH CONTAMINANT AND WEEK.

Contaminant	Week	Treatment 1	Treatment 2	*Pohlia drummondii*	*Physcomitrium patens*
Fe	2	control	dipping	0.123	0.433
		control	medium	2.551e-03 **	3.663e-04 ***
		dipping	medium	3.712e-05 ***	6.653e-04 ***
	4	control	dipping	0.41	0.024
		control	medium	4.795e-06 ***	3.125e-05 ***
		dipping	medium	1.637e-06 ***	0.021
	6	control	dipping	0.029	0.366
		control	medium	0.127	1.324e-03 **
		dipping	medium	1.180e-03 **	3.882e-03 **
	8	control	dipping	0.024	0.271
		control	medium	0.025	0.487
		dipping	medium	4.338e-05 ***	0.281
Mn	2	control	dipping	0.033	9.453e-07 ***
		control	medium	8.219e-06 ***	1.422e-03 **
		dipping	medium	3.883e-10 ***	4.634e-15 ***
	4	control	dipping	1.932e-03 **	0.038
		control	medium	3.937e-05 ***	3.103e-07 ***
		dipping	medium	0.145	7.101e-12 ***
	6	control	dipping	0.166	0.342
		control	medium	0.137	7.521e-06 ***
		dipping	medium	0.02	1.095e-06 ***
	8	control	dipping	0.245	1.481e-36 ***
		control	medium	0.241	0.024
		dipping	medium	0.495	1.520e-26 ***
As	2	control	dipping	5.037e-07 ***	4.026e-03 **
		control	medium	1.310e-03 **	0.141
		dipping	medium	1.401e-15 ***	1.110e-04 ***
	4	control	dipping	0.19	0.13
		control	medium	0.015	2.990e-03 **
		dipping	medium	0.099	0.061
	6	control	dipping	0.116	0.129
		control	medium	0.128	0.072
		dipping	medium	0.477	5.392e-03 **
	8	control	dipping	0.061	8.844e-03 **
		control	medium	0.419	0.262
		dipping	medium	0.04	1.396e-03 **
Sb	2	control	dipping	7.973e-08 ***	0.096
		control	medium	0.266	1.580e-09 ***
		dipping	medium	1.942e-06 ***	2.435e-13 ***

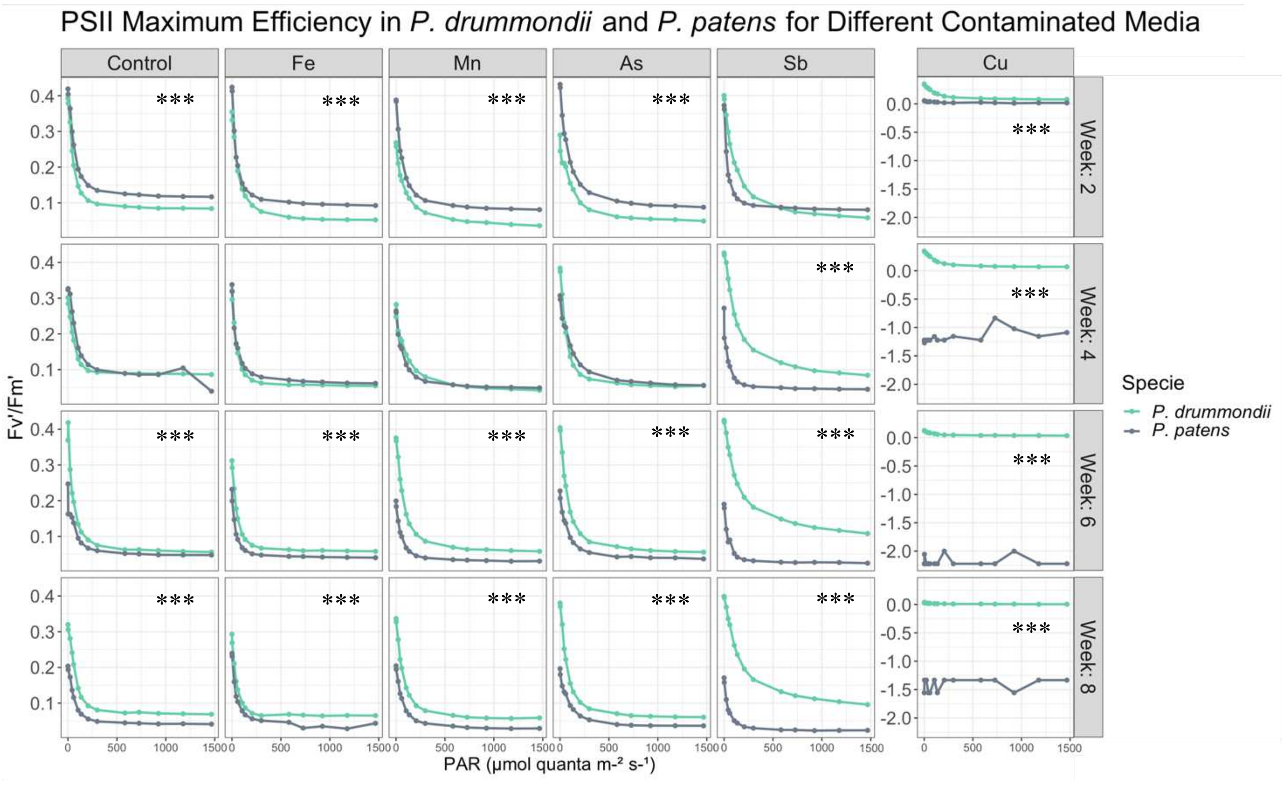
Contaminant	Week	Treatment 1	Treatment 2	*Pohlia drummondii*	*Physcomitrium patens*
Sb	4	control	dipping	0.471	0.064
		control	medium	6.740e-07 ***	3.219e-16 ***
		dipping	medium	4.687e-07 ***	2.730e-11 ***
	6	control	dipping	0.166	0.069
		control	medium	0.137	2.706e-09 ***
		dipping	medium	0.02	1.291e-13 ***
	8	control	dipping	0.095	0.301
		control	medium	1.270e-09 ***	2.060e-09 ***
		dipping	medium	1.668e-06 ***	4.185e-08 ***
Cu	2	control	dipping	4.472e-08 ***	7.086e-04 ***
		control	medium	0.187	1.895e-41 ***
		dipping	medium	8.536e-06 ***	6.329e-25 ***
	4	control	dipping	0.116	6.361e-04 ***
		control	medium	0.211	5.849e-54 ***
		dipping	medium	0.36	1.563e-34 ***
	6	control	dipping	1.207e-03 **	0.039
		control	medium	2.833e-12 ***	5.746e-49 ***
		dipping	medium	4.134e-23 ***	2.253e-38 ***
	8	control	dipping	0.486	0.016
		control	medium	2.173e-34 ***	2.516e-50 ***
		dipping	medium	1.452e-34 ***	1.938e-37 ***

TABLE 7: SIGNIFICANCE LEVELS BETWEEN TREATMENTS FOR EACH WEEK AND CONTAMINANT IN *POHLIA DRUMMONDII* AND *PHYSCOMITRIUM PATENS*. $\alpha = 0.01$, " ** " P_VALUE < 0.01, " *** " P_VALUE < 0.001.

Comparison Between Species

The differences between *P. drummondii* and *P. patens* for the contaminated medium treatment are shown in *Graph 10*. As indicated by the asterisks, there were significant differences in the reactions of the two species for all tested contaminants, as well as in the control treatment. Overall, results from As, Fe and Mn were similar to those obtained by comparing the control results, with the only non-statistically significant differences occurring at Week 4. Looking at the curves, in all four cases the Fv'/Fm' values of *P. patens* were higher than those of *P. drummondii* at Week 2, only for this trend to reverse in the following measurements. The starting value followed a similar shift, with *P. patens* having higher values than *P. drummondii* at Week 2, only for those values to drop later, leaving *P. drummondii* as the highest between the two.

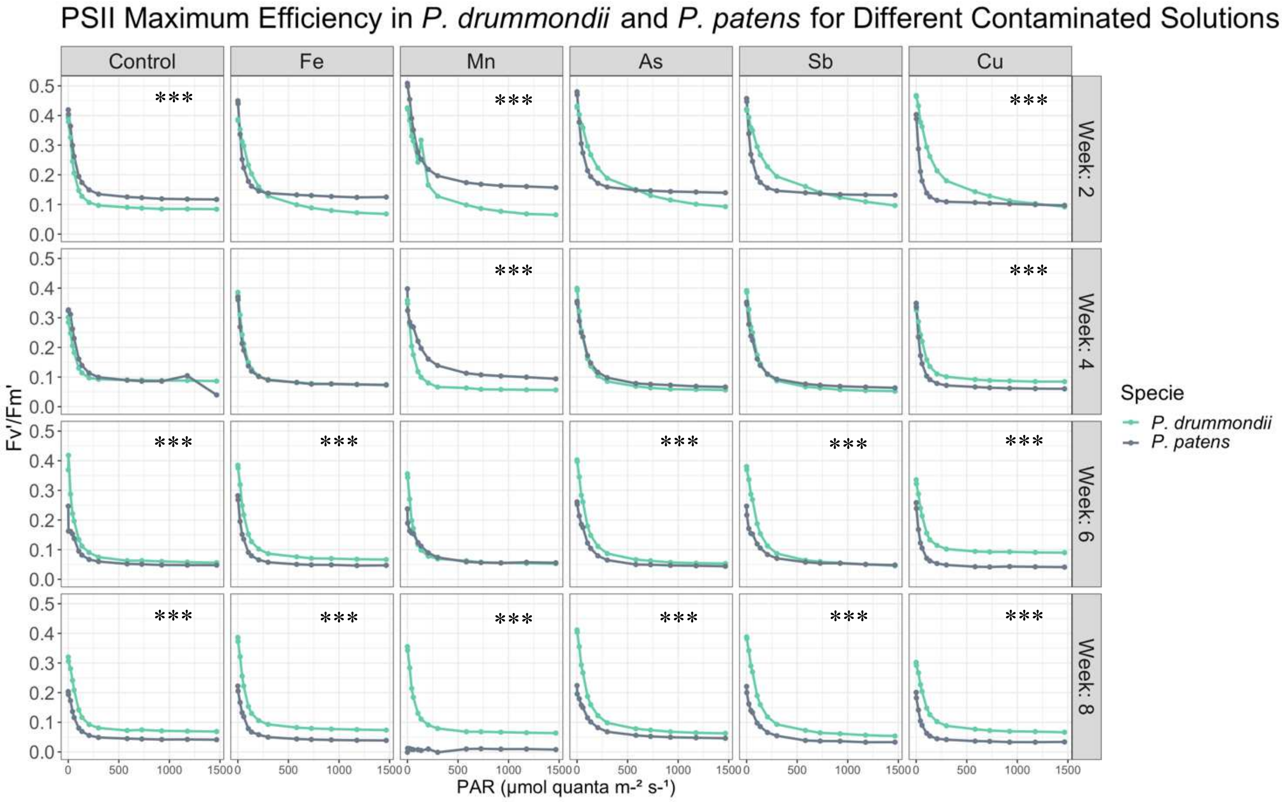
The only other case where the differences were significant at Week 2 was for Cu, where the results from *P. drummondii* were higher than *P. patens*, contrasting with the trend observed for the other contaminations. Unfortunately, due to the death of the samples after the first measurement, it was not possible to draw reliable conclusions regarding the different reactions of the two species to Cu contamination.



Graph 10: Values of PSII maximum efficiency for the contaminated medium treatment. The graph illustrates the differences between the species *Pohlia drummondii* and *Physcomitrium patens*.

The last contaminant considered was Sb, which displayed a different trend from the others, with the differences being significant only from Week 4 onwards. In this case, not only the values for *P. drummondii* were higher than those of *P. patens*, creating the largest gap among all contaminants, but the shapes of the curves were also noticeably different from each other. This was caused by the Fv'/Fm' values for *P. drummondii* not settling on a specific value but continuously decreasing with the increase of PAR, resulting in a less steep slope of the curve.

For the contaminated water solution treatment, the reactions of the two species are shown in *Graph 11*. Most of the differences between the species became significant in the last two measurements, with results for Cu being the only ones that stayed consistently statistically significant throughout the whole experiment. Other than Cu, only Mn results showed significant differences in the first four weeks, with *P. patens* having higher values than *P. drummondii*. However, this trend swapped in the final Mn measurement, in which the curve for *P. patens* lost its usual shape and settled close to zero. The responses to As, Fe and Sb contaminations shared a similar trend, with significant differences exclusively in the last two measurements, characterized by *P. drummondii* showing higher curves and starting values than *P. patens*.



GRAPH 11: VALUES OF PSII MAXIMUM EFFICIENCY FOR THE DIPPING SOLUTION TREATMENT. THE GRAPH ILLUSTRATES THE DIFFERENCES BETWEEN THE SPECIES *POHLIA DRUMMONDII* AND *PHYSCOMITRIUM PATENS*.

Week	Contaminant	Control	Medium	Dipping
2	Control	2.226e-06 ***		
	Fe		5.617e-05 ***	0.058
	Mn		8.463e-07 ***	3.424e-05 ***
	As		6.203e-08 ***	0.396
	Sb		0.08	0.031
	Cu		1.579e-22 ***	6.171e-07 ***
4	Control	0.031		
	Fe		0.036	0.204
	Mn		0.462	3.803e-07 ***
	As		0.228	0.195
	Sb		3.162e-22 ***	0.326
	Cu		1.860e-42 ***	1.270e-06 ***
6	Control	1.265e-04 ***		
	Fe		5.887e-06 ***	1.529e-08 ***
	Mn		1.285e-11 ***	0.054
	As		1.820e-07 ***	7.490e-05 ***
	Sb		2.644e-32 ***	6.762e-04 ***
	Cu		6.299e-42 ***	2.437e-15 ***
8	Control	2.063e-11 ***		
	Fe		2.471e-04 ***	2.951e-13 ***
	Mn		7.594e-08 ***	5.350e-40 ***
	As		2.208e-08 ***	3.543e-07 ***
	Sb		6.245e-33 ***	7.257e-10 ***
	Cu		1.375e-45 ***	5.704e-16 ***

TABLE 8: SIGNIFICANCE LEVELS BETWEEN *POHLIA DRUMMONDII* AND *PHYSCOMITRIUM PATENS* FOR BOTH TREATMENTS AND CONTAMINANT AT EACH WEEK. $\alpha = 0.01$ " ** " P_VALUE < 0.01 " *** " P_VALUE < 0.001

DISCUSSION

ARSENIC

For its toxicity and diffusion, As ranks first on the ATSDR 2022 Substance Priority List (ATSDR, 2022), showing the deep threat it poses to living organisms and human health. Unfortunately, As has been widely used in various industries, from manufacturing to pesticide use, leaving environmental residues that end up contaminating multiple areas around the world (Chen & Costa, 2021). Studies on plants have shown that, when present in the environment, As can limit growth, reduce fertility and decrease crop yield by negatively influencing multiple metabolic processes (Finnegan & Chen, 2012). While all forms of As exhibit some level of toxicity, its inorganic form is generally considered more harmful than its organic counterpart (Tamaki & Frankenberger, 1992). Arsenate, the chemical form used in this experiment, is one of As phytoavailable inorganic form and its uptake is being largely studied because of its chemical similarity to phosphate, which leads the two to utilize the same transportation system. Consequently, researchers have proposed that the differences in As tolerance among plant species might depend on variations of the phosphate/arsenate uptake system (Meharg & Macnair, 1992).

In the present study, the reaction to As contamination differed between the two species, but in both cases, it appeared to be the least toxic among all the considered heavy metals, especially for the contaminated medium treatment. Certain bryophytes are known to accumulate considerable levels of As in their tissues, being able to bind around 80% of the contaminant in their tissues with a binding speed depending on As concentration (Sandhi, Landberg & Greger, 2018). Nevertheless, high concentrations cause a reduction in growth and chlorophyll content in most species (Dutta *et al.*, 2024), as well as cause a drop in net photosynthetic rate over time (Díaz *et al.*, 2013). However, this was not the reaction observed in the species considered here, both of which were subjected to a high As concentration (100 μm).

While experiments on the effects of As contamination on *P. drummondii* are limited, this species has been observed growing in areas contaminated with As and other heavy metals (Adlassnig *et al.*, 2016), and members of the same genus have been identified as As hyperaccumulators (Craw *et al.*, 2007). In the case of *P. patens*, past experiments have found this species to be extremely resistant to As, only showing negative effects at concentrations higher than the one used in this study (Yin *et al.*, 2017).

These observations support the results of this study, which suggest that *P. drummondii* and *P. patens* are indeed tolerant to high concentrations of As, both from continuous contamination and from a singular event, with no changes in their reaction over time.

Copper

Cu is an essential micronutrient required by plants for photosynthesis, respiration, metabolism and various enzymatic activities. Due to its fundamental role, plants react negatively both to a deficit and an excess of Cu, which trigger numerous physiological responses that ultimately cause a reduction in growth and development (Mir, Pichtel & Hayat, 2021). Focusing on Cu toxicity, two responses of particular importance are the decrease in chlorophyll content and the damage to the chloroplast structure, which increase susceptibility to photoinhibition and lead to an overall decline in photosystem II (PSII) activity (Pätsikkä *et al.*, 2002). This negative response has also been observed in bryophytes, where high concentrations of Cu cause a reduction in both chlorophyll-a and chlorophyll-b (Shakya, Chettri & Sawidis, 2008), resulting in a decline in photosynthetic activity. However, some bryophytes are known to prefer substrates with high concentrations of copper, such as species from the genera *Scopelophila* and *Mielichhoferia* (Aikawa *et al.*, 1999).

While reactions to Cu are highly species-specific, both *P. drummondii* and *P. patens* reacted strongly to Cu contamination, with the responses to the contaminated medium treatment being more intense than those of the contaminated water solution. In fact, while the responses to the contaminated water solution treatment were mostly significant only during the first measurement, which was the closest to the one-time contamination event, the reactions to the continuous contamination intensified over time.

P. drummondii is known for its ability to survive in Cu contaminated areas, such as the mining site from which these samples originated (Adlassnig *et al.*, 2016). Nevertheless, its response to Cu was among the strongest observed across all tested heavy metals, with PSII maximum efficiency declining significantly after four weeks, reaching lower levels compared to the control (*Graph 8*). This suggests a progressive negative effect on photosystem II (PSII) activity, which intensified over time until reaching near inactivity, with Fv'/Fm' values approximating zero. This decline was even more pronounced in *P. patens*, a species known to suffer from Cu contamination with a reduction in growth under such conditions (Sassmann *et al.*, 2015). In this case, the samples started to show visible signs of stress after four weeks, ultimately ending in complete chlorosis and no detectable fluorescence activity by Week 8.

Previous studies comparing both species suggest that their different response to Cu contamination is linked to their cation exchange capacity, with *P. drummondii* having fewer binding sites and, consequently, a lower absorption capacity than *P. patens* (Antreich *et al.*, 2016). However, the limited uptake in *P. drummondii* only reduces the effects of Cu toxicity rather than completely erasing them. This hypothesis aligns with the results of this experiment, where both bryophytes reacted negatively to the contamination but to a different degree, indicating that *P. drummondii* was more tolerant to this specific heavy metal.

MANGANESE

The effects of Mn toxicity in plants have been observed for many species across multiple studies, indicating a vast range of symptoms from chlorotic leaves to root damage, often linked to growth reduction (El-Jaoual & Cox, 1998). However, it is still an essential micronutrient for a correct metabolism, which deficit poses considerable stress to plants, specifically by influencing the photosynthetic activity (Schmidt, Jensen & Husted, 2016). This is because Mn has a pivotal role in the oxygen-evolving complex (OEC) of photosystem II (PSII), which is responsible of the production of oxygen as a bioproduct of photosynthesis.

The results for both *P. drummondii* and *P. patens* show a moderate effect from Mn contamination, which however is limited to the first two and three measurement respectively. The situation differs in the contaminated water solution treatment, in which *P. patens* had an unexpectedly strong negative reaction during the final measurement at Week 8, resulting in a PSII maximum efficiency close to zero (*Graph 11*). This was surprising, as in this treatment, for all other contaminants and for both species, the samples responded significantly only during the first or second measurements, with later values resembling those of the control. Moreover, the samples did not show any visible sign of stress, unlike the ones exposed to the Cu contaminated medium. Previous studies have observed species of the genus *Physcomitrium* growing in Mn contaminated areas (Ma, Zhang & Wang, 2024), supporting the hypothesis of *P. patens* having some level of resistance to this particular heavy metal. Given these observations, a deeper study on the effect of Mn contamination in *P. patens* is needed to determine whether the measured response was caused by external factors or if the Mn absorbed during the dipping event had a delayed negative effect on the plants.

The situation for *P. drummondii* was clearer, with results indicating a higher degree of tolerance. This conclusion is consistent with previous field studies, in which *P. drummondii* was reported growing in areas characterized by high concentrations of Mn (Adlassnig *et al.*, 2016). Lastly, as observed with the other contaminants, the responses of *P. drummondii* to the contaminated medium treatment were stronger than those of the contaminated water solution treatment, a trend shared also with *P. patens*.

IRON

Among all considered heavy metals, Fe is by far the most naturally abundant in the Earth's crust. Despite its diffusion, the weathering process releases Fe in oxidized forms, mostly Fe(III), which are highly insoluble and not easily bioavailable. Consequently, plants employ different strategies to transform Fe in more soluble forms that can be easily absorbed (Guerinot & Yi, 1994). When there is not enough Fe available, plants develop numerous complications, with one of the most recognizable symptoms being chlorosis. This is because Fe is essential to the synthesis of chlorophyll, resulting in a decrease of pigmentation and photosynthesis when the plant is in deficit. Like the previous heavy metals, high levels of Fe also produce negative responses in plants, such as growth decline, influence on the assimilation of other micronutrients and a negative impact on the photosynthesis process (Zahra *et al.*, 2021).

The effect of Fe was not particularly strong on either species, with both *P. drummondii* and *P. patens* showing no response to the contaminated water treatment and very limited when growing on the contaminated medium. In the case of the contaminated medium treatment, the PSII maximum efficiency of both species resulted slightly lower than the control, indicating a possible negative effect, which however was often non-significant. While these results were consistent with other experiments for *P. patens*, the effect of Fe on *P. drummondii* was less intense than previously reported, with no significant changes over time (Schillaci, Djakovic & Lang, 2023). Moreover, the values of PSII maximum efficiency for both species and treatments suggest *P. drummondii* as the most resistant between the two, with *P. patens* showing a better response only during the first measurement (*Graph 10* and *Graph 11*).

ANTIMONY

While less studied than other heavy metals such as As, Sb is still considered toxic even at low concentrations with no known role in any biological function (Smichowski, 2008). Originating from both natural and anthropogenic sources, the extent of its impact on human health remains under investigation (Lai *et al.*, 2022).

Several experiments have been done on Sb accumulation in plants, showing different trends depending on the chemical form of the heavy metal as well as the considered species (Qi *et al.*, 2011; Shtangeeva, Steinnes & Lierhagen, 2012). While some hyperaccumulator species have been identified in contaminated areas such as mining sites (Feng *et al.*, 2013), high levels of Sb produce multiple negative effects in most plants. These include an overall reduction in growth, a negative influence on the photosynthesis process and disruptions in the uptake of micronutrients, with the severity of these effects increasing alongside Sb levels (Shtangeeva, Bali & Harris, 2011). Despite this, much remains unknown about the mechanism of Sb absorption.

Previous experiments focusing on the effects of Sb contamination reported reductions in pigment content and chloroplast function, leading to decreased values of PSII maximum efficiency (Zhou *et al.*, 2018). This was not the case for *P. drummondii*, whose response to the Sb contaminated medium was an increase in Fv'/Fm' values (*Graph 8*). A positive effect on certain parameters or metabolic pathways in the presence of low concentrations of heavy metals has been observed in various contaminants and species, a phenomenon known as hormesis. However, such positive responses are usually temporary, with stress symptoms developing under prolonged exposure or increased contamination levels (Morkunas *et al.*, 2018). In the case of *P. drummondii* the increase in PSII maximum efficiency was limited, with no significant growth after Week 4 (*Table 6*). This supports the hypothesis of a possible hermetic effect, which requires further investigation through longer experiments at different Sb concentrations. By contrast, the response of *P. patens* to Sb contamination in the contaminated medium treatment was a decrease in PSII maximum efficiency, consistent with the expected stress response to a toxic heavy metal.

The contaminated water solution treatment provoked little to no response in either species (*Table 7*), while prolonged exposure to Sb in the contaminated medium treatment, as reported in the previous paragraph, resulted in intense reactions. However, the type of response differed between the two, leading to the conclusion that *P. drummondii* and *P. patens* react differently to Sb contamination.

COMPARISON BETWEEN CONTAMINANTS

While comparing the effects of each individual contaminant across the two species and treatments, some heavy metals were found to provoke very similar reactions in the plants, as indicated by the lack of significant differences detected by the statistical analysis. This was more evident in *P. drummondii*, supporting the hypothesis that this species is more resistant to various types of contamination than *P. patens*. In the specific, in the contaminated medium treatment its responses to As, Fe and Mn were extremely similar (*Table 5*). These results are consistent with previous field based studies, in which *P. drummondii* was found resistant to high concentrations of all three heavy metals as well as Sb (Adlassnig *et al.*, 2016), for which the response in this study requires more exploration. A similar pattern was also observed in *P. patens*, although in this case the responses to As and Mn were less homogeneous.

Since As and Sb were the only heavy metals in this study that are not used as micronutrient by plants, they were expected to cause a negative response in both species, potentially even stronger than those caused by the other contaminants. However, despite their similar chemical proprieties (Arai, 2010), that was not the case. In the contaminated medium treatment, the response to Sb contamination was stronger in both species, confirming Sb as the most influential contaminant compared to As.

Overall, among all the five heavy metals tested, Cu caused the most intense reaction in both *P. drummondii* and *P. patens*. In both species, the lowest values of PSII maximum efficiency were recorded for the Cu contaminated medium, with samples from *P. patens* showing visible symptoms of stress such as chlorosis and limited growth. Despite being an essential micronutrient, the damaging effect of Cu contamination on bryophytes has been reported in multiple studies, with some species being generally more tolerant to toxic heavy metals such as As and Sb than to Cu (Adlassnig *et al.*, 2016). Because of such an intense response in both species, the results from Cu contamination were consistently different from those of all other contaminants under the contaminated medium treatment.

The results in the contaminated solution treatment were different from those observed in the contaminated medium treatment. *P. drummondii* showed a homogenization of the responses to the various contaminants over time, suggesting a broader tolerance range. The reactions of *P. patens* were more varied, with only the contaminations from As, Fe and Sb producing similar responses (*Table 5*). The most notable response was towards Mn contamination, which was the only one to show a sharp decrease in PSII maximum efficiency during the final measurement. Overall, all samples of *P. patens* including the control showed a decline in both PSII maximum efficiency and the initial Fv'/Fm' values over time. Since this trend was also observed in the control, it might reflect the normal progression for *P. patens* or a response to an unidentified stress not considered during this experiment. One possibility is a failed adaptation to the laboratory conditions, as samples of *P. patens* were employed in the experiment only two weeks after arrival, whereas *P. drummondii* was propagated multiple times over several months prior to this study.

For all heavy metals, both *P. drummondii* and *P. patens* reacted more intensely to the contaminated medium treatment, confirming that prolonged contact causes a higher reaction than a brief contamination event such as for the contaminated solution treatment. This suggests that the method of contamination does indeed influence the response of both species to all five heavy metals considered. Studies on bryophytes comparing such treatments are scarce, as most experiments focus exclusively on the effects of contaminated media as a form of continuous contamination. However, the work of Sidhu and Brown (1996) examined differences between contamination methods, with one simulating substrata contamination and the other rainfall and aerial contamination. Although these methods differed from those used in this study, all aimed to replicate the environmental conditions in which bryophytes are exposed to pollutants in the wild. In both studies, plants responded to the non-continuous treatment, dipping in water solution in this case, mostly during the initial period of the experiment, with later measurements showing minimal changes.

CONCLUSIONS

Both *P. drummondii* and *P. patens* demonstrated varying levels of tolerance towards all tested heavy metals except Cu, which provoked the most intense and negative response in both species, leading to a marked decrease in their PSII maximum efficiency. The intensity of the reactions to the contaminations differed between the species, with *P. patens* showing more pronounced responses to the tested contaminants compared to *P. drummondii*. Consequently, it can be concluded that *P. drummondii* is overall more tolerant to heavy metal contamination than *P. patens*. The experiment also highlighted the method of contamination as a key factor influencing plant tolerance, confirming that a prolonged exposure intensifies the negative effects on the plants. However, several heavy metals showed no apparent impact on the photosynthetic activity of either species, both in the contaminated medium treatment and in the contaminated water solution treatment.

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SUPPLEMENTARY MATERIAL

On the following pages the data used for all the graphs and calculations are reported. These data result from a first cleaning of the raw data provided by the IMAGING-PAM chlorophyll fluorometer. During this first manipulation, only the minimal (Fo') and maximal (Fm') fluorescence values for light-adapted leaves were kept and used to calculate the variable fluorescence (Fv') and the PSII maximum efficiency (Fv'/Fm') (*Table 4*). The provided data show values of Fv'/Fm' with the corresponding standard deviation for all measurements across the 14 levels of Photosynthetically Active Radiation (PAR) utilized by the instrument. More details can be found in the Photosynthetic Measurement section on page 13.

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
control	Control	2	0	0.39284362	0.05052307	0.41916269	0.02432086
control	Control	2	2	0.37865166	0.05848521	0.40393783	0.02393837
control	Control	2	22	0.32617304	0.04772204	0.36405868	0.02724511
control	Control	2	42	0.2454617	0.04514928	0.29930526	0.03224337
control	Control	2	58	0.20581966	0.04025111	0.26198	0.0308932
control	Control	2	104	0.14682195	0.03208306	0.19440033	0.02401848
control	Control	2	135	0.12747826	0.02713856	0.17389197	0.02101002
control	Control	2	206	0.10654116	0.02136198	0.14889057	0.01588506
control	Control	2	299	0.09677531	0.018205	0.13480852	0.01272685
control	Control	2	582	0.08998691	0.01438379	0.12518881	0.00899932
control	Control	2	727	0.08747786	0.01449082	0.12271255	0.00959936
control	Control	2	924	0.08486841	0.01578769	0.118978	0.00884315
control	Control	2	1177	0.08481634	0.01533546	0.11775356	0.00841708
control	Control	2	1467	0.08400291	0.01405059	0.11687335	0.00923324
control	Control	4	0	0.30166329	0.03787334	0.32374578	0.01764424
control	Control	4	2	0.28465728	0.03563998	0.32666235	0.01662493
control	Control	4	22	0.24777402	0.02760725	0.31172612	0.019684
control	Control	4	42	0.20562101	0.02338443	0.26247338	0.03125726
control	Control	4	58	0.18235092	0.02483826	0.23035104	0.03172697
control	Control	4	104	0.13001874	0.02313927	0.16100743	0.02151461
control	Control	4	135	0.11409244	0.02101889	0.13911835	0.01615586
control	Control	4	206	0.09712583	0.01640706	0.11355499	0.01263928
control	Control	4	299	0.09277097	0.01672497	0.09939433	0.0084309
control	Control	4	582	0.08954268	0.01597684	0.08934466	0.00552267
control	Control	4	727	0.08954345	0.01590086	0.08599344	0.00442683
control	Control	4	924	0.08817468	0.01636297	0.08606428	0.0120038
control	Control	4	1177	0.0881246	0.01654969	0.10457862	0.0633132
control	Control	4	1467	0.08632759	0.01672668	0.03957689	0.14680985

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
control	Control	6	0	0.369180118	0.047716613	0.246880859	0.022274592
control	Control	6	2	0.418279113	0.083226658	0.162414941	0.048057178
control	Control	6	22	0.287230169	0.052404765	0.161686179	0.037096751
control	Control	6	42	0.2211537	0.058701662	0.152835997	0.019197399
control	Control	6	58	0.196599414	0.055507484	0.137940838	0.016357669
control	Control	6	104	0.134088749	0.040543533	0.094931884	0.010612069
control	Control	6	135	0.112049822	0.033450324	0.081622351	0.00794837
control	Control	6	206	0.090110397	0.021864085	0.06688092	0.005653822
control	Control	6	299	0.074749433	0.020668969	0.05994179	0.007273649
control	Control	6	582	0.06274483	0.012916916	0.05194469	0.00517135
control	Control	6	727	0.062880047	0.012713585	0.050768369	0.004295782
control	Control	6	924	0.060264962	0.011777174	0.048354414	0.005006068
control	Control	6	1177	0.057852567	0.010349741	0.047899053	0.004783831
control	Control	6	1467	0.05607245	0.011017962	0.047700156	0.004819503
control	Control	8	0	0.319977005	0.030504424	0.203436508	0.015485948
control	Control	8	2	0.306019493	0.030713869	0.193391143	0.014436799
control	Control	8	22	0.281088938	0.029195338	0.172965902	0.01429337
control	Control	8	42	0.24134392	0.030718089	0.13642654	0.011726274
control	Control	8	58	0.208451057	0.029836487	0.115853328	0.010630365
control	Control	8	104	0.141628779	0.024838438	0.080229768	0.009478348
control	Control	8	135	0.116482351	0.019845198	0.06911118	0.009161564
control	Control	8	206	0.092594006	0.014509016	0.055617666	0.007949342
control	Control	8	299	0.080764458	0.008261758	0.048737054	0.005962883
control	Control	8	582	0.072361526	0.008403101	0.04490385	0.003475981
control	Control	8	727	0.074449841	0.006291746	0.043623279	0.005321197
control	Control	8	924	0.071147545	0.007428814	0.041801961	0.004636002
control	Control	8	1177	0.070046599	0.006849789	0.0421892	0.004951294
control	Control	8	1467	0.068782011	0.006580754	0.041133402	0.004934837

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	As	6	0	0.40444027	0.040794013	0.227317512	0.012759717
medium	As	6	2	0.396041383	0.041267806	0.206502456	0.013478418
medium	As	6	22	0.335477686	0.055191911	0.167909098	0.019805854
medium	As	6	42	0.268870536	0.068586968	0.144435715	0.021105681
medium	As	6	58	0.241471799	0.061892537	0.136504431	0.018913711
medium	As	6	104	0.168147833	0.049150617	0.096876464	0.012163867
medium	As	6	135	0.141130303	0.043052175	0.082561085	0.009338343
medium	As	6	206	0.107755315	0.032907942	0.064725112	0.00885916
medium	As	6	299	0.084525593	0.025716095	0.054690546	0.006744741
medium	As	6	582	0.071316178	0.017558002	0.042517548	0.00596712
medium	As	6	727	0.065030622	0.015284703	0.043657486	0.005099552
medium	As	6	924	0.060398143	0.01415583	0.040151319	0.005523008
medium	As	6	1177	0.057510445	0.015582416	0.039800861	0.003805775
medium	As	6	1467	0.056025151	0.014776559	0.036939609	0.00532166
medium	As	8	0	0.380170777	0.087513914	0.19649449	0.024919783
medium	As	8	2	0.370287651	0.090457199	0.179905065	0.023918642
medium	As	8	22	0.320616675	0.073733551	0.148097579	0.022188311
medium	As	8	42	0.251706443	0.054372199	0.13144138	0.021195575
medium	As	8	58	0.222248122	0.050711991	0.125770162	0.020292568
medium	As	8	104	0.15501166	0.044122109	0.093284961	0.017164006
medium	As	8	135	0.131350613	0.038346236	0.082159252	0.014331621
medium	As	8	206	0.101939346	0.029219786	0.063956547	0.011535985
medium	As	8	299	0.083940043	0.022278071	0.05319098	0.009672065
medium	As	8	582	0.070637703	0.014808447	0.040290013	0.007993268
medium	As	8	727	0.065112579	0.013868587	0.03796781	0.007197442
medium	As	8	924	0.063141056	0.014663547	0.037005072	0.005456719
medium	As	8	1177	0.061428878	0.013015068	0.036745338	0.006930199
medium	As	8	1467	0.060636521	0.012319309	0.036540145	0.006441263

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	As	2	0	0.289855893	0.034119293	0.431760097	0.020454365
medium	As	2	2	0.244980841	0.038870218	0.422638001	0.019807382
medium	As	2	22	0.211706758	0.036792886	0.345087216	0.038905426
medium	As	2	42	0.211083152	0.031737302	0.294039644	0.045432267
medium	As	2	58	0.201083659	0.030099014	0.276995909	0.039146022
medium	As	2	104	0.155020856	0.029796718	0.213803144	0.031357069
medium	As	2	135	0.137198918	0.026001158	0.18685578	0.027424632
medium	As	2	206	0.100371753	0.018665787	0.151609686	0.022360549
medium	As	2	299	0.080500763	0.012734288	0.128519187	0.019283129
medium	As	2	582	0.060963349	0.007724575	0.104854595	0.013432696
medium	As	2	727	0.057796301	0.00589241	0.098806852	0.01307526
medium	As	2	924	0.054886249	0.00689771	0.093109702	0.012012326
medium	As	2	1177	0.053019755	0.005858427	0.091336754	0.011872171
medium	As	2	1467	0.04912307	0.005834721	0.087850167	0.011020679
medium	As	4	0	0.384094355	0.045072965	0.307135398	0.019719387
medium	As	4	2	0.374426486	0.049618329	0.296247139	0.018871561
medium	As	4	22	0.311025667	0.051403364	0.243689779	0.024307701
medium	As	4	42	0.231532816	0.056156504	0.222915829	0.031479317
medium	As	4	58	0.20407558	0.050404924	0.217934776	0.031670849
medium	As	4	104	0.136049706	0.03615872	0.167145171	0.031012648
medium	As	4	135	0.111932013	0.030838702	0.145157773	0.025571224
medium	As	4	206	0.086363794	0.022307329	0.113544583	0.021526941
medium	As	4	299	0.073490536	0.016664725	0.093528974	0.017621299
medium	As	4	582	0.062335474	0.013509778	0.070392626	0.011860325
medium	As	4	727	0.05794259	0.014903703	0.066582712	0.011991018
medium	As	4	924	0.055205485	0.013309118	0.062354792	0.011437378
medium	As	4	1177	0.052360629	0.014022364	0.057536054	0.009244729
medium	As	4	1467	0.054887799	0.01460287	0.055994721	0.010469517

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	As	6	0	0.40444027	0.040794013	0.227317512	0.012759717
medium	As	6	2	0.396041383	0.041267806	0.206502456	0.013478418
medium	As	6	22	0.335477686	0.055191911	0.167909098	0.019805854
medium	As	6	42	0.268870536	0.068586968	0.144435715	0.021105681
medium	As	6	58	0.241471799	0.061892537	0.136504431	0.018913711
medium	As	6	104	0.168147833	0.049150617	0.096876464	0.012163867
medium	As	6	135	0.141130303	0.043052175	0.082561085	0.009338343
medium	As	6	206	0.107755315	0.032907942	0.064725112	0.00885916
medium	As	6	299	0.084525593	0.025716095	0.054690546	0.006744741
medium	As	6	582	0.071316178	0.017558002	0.042517548	0.00596712
medium	As	6	727	0.065030622	0.015284703	0.043657486	0.005099552
medium	As	6	924	0.060398143	0.01415583	0.040151319	0.005523008
medium	As	6	1177	0.057510445	0.015582416	0.039800861	0.003805775
medium	As	6	1467	0.056025151	0.014776559	0.036939609	0.00532166
medium	As	8	0	0.380170777	0.087513914	0.19649449	0.024919783
medium	As	8	2	0.370287651	0.090457199	0.179905065	0.023918642
medium	As	8	22	0.320616675	0.073733551	0.148097579	0.022188311
medium	As	8	42	0.251706443	0.054372199	0.13144138	0.021195575
medium	As	8	58	0.222248122	0.050711991	0.125770162	0.020292568
medium	As	8	104	0.15501166	0.044122109	0.093284961	0.017164006
medium	As	8	135	0.131350613	0.038346236	0.082159252	0.014331621
medium	As	8	206	0.101939346	0.029219786	0.063956547	0.011535985
medium	As	8	299	0.083940043	0.022278071	0.05319098	0.009672065
medium	As	8	582	0.070637703	0.014808447	0.040290013	0.007993268
medium	As	8	727	0.065112579	0.013868587	0.03796781	0.007197442
medium	As	8	924	0.063141056	0.014663547	0.037005072	0.005456719
medium	As	8	1177	0.061428878	0.013015068	0.036745338	0.006930199
medium	As	8	1467	0.060636521	0.012319309	0.036540145	0.006441263

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Cu	2	0	0.350352945	0.146501909	0.054524622	0.125494188
medium	Cu	2	2	0.337312023	0.141282331	0.05604508	0.109505308
medium	Cu	2	22	0.29732546	0.125850733	0.03972694	0.084088781
medium	Cu	2	42	0.273758029	0.11662095	0.037569887	0.073045507
medium	Cu	2	58	0.252075524	0.107656722	0.040501927	0.073738459
medium	Cu	2	104	0.193531326	0.086352658	0.033389545	0.06838284
medium	Cu	2	135	0.176701792	0.093449383	0.030103435	0.061758051
medium	Cu	2	206	0.134687155	0.066902573	0.020916861	0.050187001
medium	Cu	2	299	0.115074417	0.053235723	0.019190895	0.046163842
medium	Cu	2	582	0.096308749	0.04250565	0.026296296	0.033017018
medium	Cu	2	727	0.08996087	0.039153393	0.018888889	0.030184617
medium	Cu	2	924	0.085478315	0.038855474	0.011481481	0.041469906
medium	Cu	2	1177	0.080075008	0.03687721	0.017407407	0.026965914
medium	Cu	2	1467	0.078497391	0.034898804	0.017407407	0.026965914
medium	Cu	4	0	0.346572605	0.148003532	-1.222222222	0.440958552
medium	Cu	4	2	0.336218116	0.144139451	-1.27037037	0.73568646
medium	Cu	4	22	0.304524817	0.133215111	-1.222222222	0.440958552
medium	Cu	4	42	0.271715138	0.120347922	-1.222222222	0.440958552
medium	Cu	4	58	0.251537591	0.112581008	-1.222222222	0.440958552
medium	Cu	4	104	0.187658094	0.086809328	-1.159259259	0.848491763
medium	Cu	4	135	0.15687012	0.07113934	-1.222222222	0.440958552
medium	Cu	4	206	0.125390657	0.058400131	-1.222222222	0.440958552
medium	Cu	4	299	0.103289668	0.049181614	-1.155555556	0.51747249
medium	Cu	4	582	0.083609003	0.038394287	-1.222222222	0.440958552
medium	Cu	4	727	0.076298607	0.037063333	-0.833333333	0.612372436
medium	Cu	4	924	0.072991002	0.033438379	-1.022222222	0.620035841
medium	Cu	4	1177	0.069929247	0.031084451	-1.155555556	0.51747249
medium	Cu	4	1467	0.069277347	0.030345	-1.088888889	0.57542255

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Cu	6	0	0.124147724	0.09815305	-2.222222222	0.666666667
medium	Cu	6	2	0.119358079	0.093119678	-2.055555556	0.881917104
medium	Cu	6	22	0.098601621	0.077395376	-2.222222222	0.666666667
medium	Cu	6	42	0.084859183	0.064574979	-2.222222222	0.666666667
medium	Cu	6	58	0.082107564	0.059776339	-2.222222222	0.666666667
medium	Cu	6	104	0.068064886	0.053488341	-2.222222222	0.666666667
medium	Cu	6	135	0.059444886	0.052210084	-2.222222222	0.666666667
medium	Cu	6	206	0.046946175	0.043596964	-2	0.707106781
medium	Cu	6	299	0.044639123	0.029642217	-2.222222222	0.666666667
medium	Cu	6	582	0.038796419	0.020323516	-2.222222222	0.666666667
medium	Cu	6	727	0.039470601	0.027400424	-2.222222222	0.666666667
medium	Cu	6	924	0.037426471	0.027148076	-2	0.707106781
medium	Cu	6	1177	0.037426471	0.027148076	-2.222222222	0.666666667
medium	Cu	6	1467	0.034310345	0.021946241	-2.222222222	0.666666667
medium	Cu	8	0	0.02973301	0.084097651	-1.555555556	0.726483157
medium	Cu	8	2	0.036818182	0.104137544	-1.333333333	0.5
medium	Cu	8	22	0.022959184	0.064938378	-1.333333333	0.5
medium	Cu	8	42	0.019685039	0.055677699	-1.555555556	0.726483157
medium	Cu	8	58	0.019067797	0.053931873	-1.555555556	0.726483157
medium	Cu	8	104	0.014204545	0.040176522	-1.333333333	0.5
medium	Cu	8	135	0.013513514	0.038221988	-1.555555556	0.726483157
medium	Cu	8	206	0.01171875	0.03314563	-1.333333333	0.5
medium	Cu	8	299	0.007653061	0.021646126	-1.333333333	0.5
medium	Cu	8	582	0.008522727	0.024105913	-1.333333333	0.5
medium	Cu	8	727	0.006410256	0.018130943	-1.333333333	0.5
medium	Cu	8	924	0.006410256	0.018130943	-1.555555556	0.726483157
medium	Cu	8	1177	0.003676471	0.010398629	-1.333333333	0.5
medium	Cu	8	1467	0.003676471	0.010398629	-1.333333333	0.5

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Fe	2	0	0.354589066	0.061841551	0.423822933	0.046980118
medium	Fe	2	2	0.331777683	0.073110543	0.412953701	0.050873064
medium	Fe	2	22	0.284794554	0.071668766	0.30163951	0.036361735
medium	Fe	2	42	0.227030709	0.058034219	0.227489856	0.035154811
medium	Fe	2	58	0.189300265	0.045316689	0.204323002	0.033737645
medium	Fe	2	104	0.138581911	0.033925098	0.154696309	0.028821428
medium	Fe	2	135	0.119347309	0.030237282	0.137948896	0.025497314
medium	Fe	2	206	0.093051553	0.024410233	0.121854814	0.02103739
medium	Fe	2	299	0.075523765	0.019205642	0.109752971	0.018951667
medium	Fe	2	582	0.05976685	0.013933865	0.10218583	0.015605216
medium	Fe	2	727	0.056061279	0.013498309	0.098151123	0.016199443
medium	Fe	2	924	0.053784318	0.013354205	0.095990742	0.014677674
medium	Fe	2	1177	0.052811822	0.011703421	0.094258997	0.014697082
medium	Fe	2	1467	0.052313143	0.010724035	0.092482296	0.013365799
medium	Fe	4	0	0.320104691	0.075242033	0.337989895	0.053140699
medium	Fe	4	2	0.296182773	0.090986728	0.318765425	0.051859081
medium	Fe	4	22	0.231388457	0.058809201	0.216450801	0.04055077
medium	Fe	4	42	0.170426684	0.036303044	0.172973302	0.045263683
medium	Fe	4	58	0.146597168	0.028259698	0.16030285	0.041338806
medium	Fe	4	104	0.100752151	0.023109104	0.117356391	0.031378124
medium	Fe	4	135	0.085774074	0.018749543	0.103134114	0.026660213
medium	Fe	4	206	0.070120638	0.018897976	0.088230902	0.021783099
medium	Fe	4	299	0.06213516	0.017852255	0.078910615	0.019457751
medium	Fe	4	582	0.057218799	0.017023184	0.070917742	0.017490248
medium	Fe	4	727	0.057811202	0.013289144	0.067239404	0.015461148
medium	Fe	4	924	0.056789329	0.013626048	0.065200087	0.014830154
medium	Fe	4	1177	0.054905813	0.01466007	0.062384376	0.014304373
medium	Fe	4	1467	0.054607089	0.012456602	0.061593524	0.014082605

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Fe	6	0	0.31185164	0.08466768	0.231908031	0.031108036
medium	Fe	6	2	0.292309022	0.088136596	0.198957178	0.028504248
medium	Fe	6	22	0.233785332	0.064886718	0.146618926	0.028619996
medium	Fe	6	42	0.177361635	0.046993461	0.105846085	0.024164529
medium	Fe	6	58	0.14988143	0.039586731	0.091646921	0.019536033
medium	Fe	6	104	0.105439822	0.030546262	0.068114419	0.015005875
medium	Fe	6	135	0.090996013	0.024999977	0.060520445	0.012144352
medium	Fe	6	206	0.074969969	0.023329494	0.051050167	0.010527825
medium	Fe	6	299	0.067007423	0.022809236	0.047566453	0.010489537
medium	Fe	6	582	0.062783716	0.018488777	0.043887731	0.009875203
medium	Fe	6	727	0.059786555	0.019299645	0.043614751	0.008979295
medium	Fe	6	924	0.060561653	0.01889534	0.04208055	0.009514028
medium	Fe	6	1177	0.059123251	0.018790788	0.041159101	0.009593284
medium	Fe	6	1467	0.058099162	0.019278443	0.040347882	0.009877048
medium	Fe	8	0	0.292886508	0.100839937	0.239286194	0.022716597
medium	Fe	8	2	0.268868818	0.098024664	0.231351697	0.037687899
medium	Fe	8	22	0.210776125	0.072946381	0.159816935	0.021416411
medium	Fe	8	42	0.1610172	0.051841714	0.118862269	0.019941442
medium	Fe	8	58	0.137632541	0.045620751	0.104011305	0.016131245
medium	Fe	8	104	0.10053653	0.035947049	0.078200966	0.011920004
medium	Fe	8	135	0.086631914	0.033141721	0.067025376	0.010615024
medium	Fe	8	206	0.071346888	0.028851627	0.056052719	0.00924645
medium	Fe	8	299	0.065217243	0.029392655	0.051034999	0.008182016
medium	Fe	8	582	0.068611843	0.02656563	0.046317446	0.008054393
medium	Fe	8	727	0.066425877	0.02618019	0.03019949	0.023532912
medium	Fe	8	924	0.064350676	0.02736677	0.035188641	0.021341427
medium	Fe	8	1177	0.065570766	0.024608886	0.02838918	0.022570321
medium	Fe	8	1467	0.065188081	0.027230263	0.043517706	0.008020489

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Mn	2	0	0.26862	0.067422444	0.387756073	0.037714082
medium	Mn	2	2	0.258069537	0.068270082	0.384250832	0.039173644
medium	Mn	2	22	0.210349676	0.059083028	0.306464774	0.033627201
medium	Mn	2	42	0.177061423	0.053863028	0.24551938	0.039982483
medium	Mn	2	58	0.162526815	0.056208303	0.225609958	0.035557821
medium	Mn	2	104	0.128408918	0.046222274	0.169368341	0.029235434
medium	Mn	2	135	0.112435618	0.042214408	0.148351824	0.025504988
medium	Mn	2	206	0.087954751	0.036860335	0.121754822	0.021235632
medium	Mn	2	299	0.072167787	0.030644402	0.106566657	0.019401456
medium	Mn	2	582	0.053495493	0.027278884	0.092682215	0.015252238
medium	Mn	2	727	0.047562101	0.023624755	0.088283521	0.015791709
medium	Mn	2	924	0.044780399	0.019461837	0.084829594	0.015799564
medium	Mn	2	1177	0.039568606	0.020527646	0.083074167	0.015155033
medium	Mn	2	1467	0.036060016	0.018414138	0.080941331	0.016024954
medium	Mn	4	0	0.247977218	0.105171078	0.264336605	0.055875101
medium	Mn	4	2	0.282227319	0.133834533	0.259856597	0.055136951
medium	Mn	4	22	0.207734955	0.102159609	0.198683447	0.029055675
medium	Mn	4	42	0.187184061	0.091564341	0.166303251	0.030628316
medium	Mn	4	58	0.179999743	0.079310901	0.158152021	0.032175669
medium	Mn	4	104	0.141823105	0.057611048	0.113744262	0.027064795
medium	Mn	4	135	0.124212948	0.04659093	0.099183501	0.024269578
medium	Mn	4	206	0.096875636	0.034715579	0.079049682	0.019003732
medium	Mn	4	299	0.079839962	0.026825492	0.067059765	0.016910171
medium	Mn	4	582	0.057524684	0.017191906	0.057530753	0.013979357
medium	Mn	4	727	0.051840211	0.016478721	0.053874709	0.013420826
medium	Mn	4	924	0.047925004	0.012492625	0.051190028	0.012914983
medium	Mn	4	1177	0.045232914	0.013435548	0.050334242	0.013094479
medium	Mn	4	1467	0.042259546	0.011067649	0.048865535	0.012574589

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Mn	6	0	0.375367286	0.12305821	0.199229018	0.028354017
medium	Mn	6	2	0.367372896	0.121062246	0.183612698	0.026501812
medium	Mn	6	22	0.322261471	0.101002334	0.142969517	0.025968441
medium	Mn	6	42	0.259658309	0.072553025	0.111195157	0.024622243
medium	Mn	6	58	0.228255795	0.056236839	0.099479747	0.021515196
medium	Mn	6	104	0.16175567	0.04197033	0.067824684	0.014034161
medium	Mn	6	135	0.13491615	0.036613567	0.057933792	0.010965081
medium	Mn	6	206	0.105707992	0.029988438	0.045480812	0.007868927
medium	Mn	6	299	0.086409502	0.025994005	0.039791642	0.00703009
medium	Mn	6	582	0.0695125	0.022431613	0.034789629	0.007560692
medium	Mn	6	727	0.063525151	0.022387119	0.033372546	0.005754564
medium	Mn	6	924	0.062896294	0.02161645	0.032212015	0.006906434
medium	Mn	6	1177	0.060195499	0.021721879	0.030333306	0.007022021
medium	Mn	6	1467	0.058099307	0.019564464	0.030737258	0.005211328
medium	Mn	8	0	0.336693101	0.113999907	0.204196551	0.01920988
medium	Mn	8	2	0.327187833	0.110166671	0.194676436	0.015008397
medium	Mn	8	22	0.278071552	0.084544318	0.160956653	0.015592936
medium	Mn	8	42	0.222334667	0.059370575	0.126456608	0.017063773
medium	Mn	8	58	0.198277108	0.048728803	0.113339879	0.014075949
medium	Mn	8	104	0.142855448	0.034859879	0.07836837	0.008944406
medium	Mn	8	135	0.122006422	0.02926523	0.06724885	0.007038464
medium	Mn	8	206	0.093091043	0.024647609	0.050436806	0.005617811
medium	Mn	8	299	0.078873856	0.021782376	0.043276966	0.002957906
medium	Mn	8	582	0.065790102	0.021967809	0.035612049	0.003194836
medium	Mn	8	727	0.060403272	0.023440721	0.03174373	0.004941496
medium	Mn	8	924	0.05823023	0.021334933	0.029885518	0.004179033
medium	Mn	8	1177	0.057256479	0.023483258	0.028700239	0.004466334
medium	Mn	8	1467	0.058691202	0.023349823	0.029176744	0.005393013

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Sb	2	0	0.400589799	0.023025971	0.372632162	0.040651543
medium	Sb	2	2	0.390328078	0.02309144	0.36185114	0.042996555
medium	Sb	2	22	0.345949828	0.029650448	0.243572439	0.038196573
medium	Sb	2	42	0.298860923	0.041742906	0.178204644	0.034249294
medium	Sb	2	58	0.264614325	0.043240949	0.160934643	0.029743775
medium	Sb	2	104	0.212856596	0.038419134	0.124295385	0.019680965
medium	Sb	2	135	0.191964261	0.036196114	0.11103286	0.017863032
medium	Sb	2	206	0.146615374	0.028120042	0.099210538	0.013714979
medium	Sb	2	299	0.116882222	0.024337337	0.092785377	0.014452553
medium	Sb	2	582	0.085156779	0.018854381	0.087756613	0.012686728
medium	Sb	2	727	0.07447518	0.014637759	0.085233305	0.012223058
medium	Sb	2	924	0.06909077	0.011368403	0.082938111	0.012008901
medium	Sb	2	1177	0.063537647	0.007782619	0.081487471	0.011737179
medium	Sb	2	1467	0.058361305	0.007247184	0.080599217	0.012444609
medium	Sb	4	0	0.426577396	0.020831752	0.272048045	0.059257341
medium	Sb	4	2	0.420435573	0.02210068	0.188473473	0.013212949
medium	Sb	4	22	0.399891826	0.025038441	0.161556521	0.0197095
medium	Sb	4	42	0.35459024	0.032674096	0.122631116	0.026986118
medium	Sb	4	58	0.323400175	0.028915871	0.109218862	0.026744897
medium	Sb	4	104	0.254692644	0.026040973	0.076611386	0.016116512
medium	Sb	4	135	0.225364736	0.024602949	0.065794346	0.013443441
medium	Sb	4	206	0.184193806	0.023630692	0.057337866	0.009539314
medium	Sb	4	299	0.154788198	0.021924265	0.052384592	0.008617134
medium	Sb	4	582	0.119411966	0.016967276	0.04944186	0.008586563
medium	Sb	4	727	0.10819711	0.016843028	0.046859887	0.008949578
medium	Sb	4	924	0.096787153	0.016724627	0.046532788	0.007870109
medium	Sb	4	1177	0.09079952	0.01503638	0.045478934	0.009237141
medium	Sb	4	1467	0.084074657	0.014564497	0.044912018	0.009324352

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
medium	Sb	6	0	0.425281278	0.028105856	0.190093108	0.031082117
medium	Sb	6	2	0.419425466	0.026704263	0.17927762	0.03102646
medium	Sb	6	22	0.389710975	0.021925781	0.120009071	0.020675458
medium	Sb	6	42	0.349867381	0.021914856	0.084435232	0.018012516
medium	Sb	6	58	0.328279378	0.020613274	0.089986148	0.012664043
medium	Sb	6	104	0.271471463	0.017174826	0.051930959	0.008840795
medium	Sb	6	135	0.247094705	0.016284671	0.041764658	0.00747632
medium	Sb	6	206	0.209437378	0.016815136	0.034672027	0.006705305
medium	Sb	6	299	0.181698902	0.016320228	0.031578798	0.005025159
medium	Sb	6	582	0.148575619	0.014076493	0.027769822	0.004179521
medium	Sb	6	727	0.135932777	0.014424946	0.026660993	0.004383545
medium	Sb	6	924	0.124712286	0.014254894	0.027381359	0.004390736
medium	Sb	6	1177	0.116616453	0.01349762	0.026908817	0.004008928
medium	Sb	6	1467	0.107823942	0.013623819	0.024942981	0.004411115
medium	Sb	8	0	0.39903711	0.034949107	0.17071308	0.051279557
medium	Sb	8	2	0.394729662	0.034272897	0.157929083	0.054563188
medium	Sb	8	22	0.368701998	0.028368342	0.110089645	0.033837253
medium	Sb	8	42	0.336361052	0.027113841	0.080959735	0.019782555
medium	Sb	8	58	0.319216045	0.023487439	0.071973449	0.015837976
medium	Sb	8	104	0.261726963	0.021801099	0.050747814	0.010001818
medium	Sb	8	135	0.236096088	0.019286885	0.044103263	0.007446899
medium	Sb	8	206	0.195701517	0.017065766	0.033706999	0.006290796
medium	Sb	8	299	0.165913031	0.016462028	0.029908169	0.004845056
medium	Sb	8	582	0.132134943	0.013210901	0.025090323	0.004845995
medium	Sb	8	727	0.120854885	0.013896617	0.024834638	0.004958778
medium	Sb	8	924	0.112315533	0.012750018	0.022967772	0.003100365
medium	Sb	8	1177	0.10389835	0.012224203	0.023611788	0.003476846
medium	Sb	8	1467	0.095853462	0.013393267	0.023831393	0.003209691

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	As	2	0	0.43137927	0.042015401	0.479871731	0.026639494
dipping	As	2	2	0.427150527	0.042280594	0.469845664	0.029705887
dipping	As	2	22	0.403534676	0.045504197	0.37733035	0.051952932
dipping	As	2	42	0.368657311	0.049482574	0.305171909	0.054548781
dipping	As	2	58	0.358443595	0.046337914	0.274091132	0.045963864
dipping	As	2	104	0.296629036	0.043189819	0.21410902	0.032161374
dipping	As	2	135	0.267807453	0.041832308	0.193771607	0.026187281
dipping	As	2	206	0.223012665	0.042291876	0.171313774	0.018287146
dipping	As	2	299	0.188156549	0.04157586	0.158756333	0.014564856
dipping	As	2	582	0.150290714	0.039746728	0.14795248	0.011747745
dipping	As	2	727	0.130089355	0.037063589	0.146143642	0.010993935
dipping	As	2	924	0.115032466	0.031895738	0.143463591	0.010906646
dipping	As	2	1177	0.100803617	0.028981765	0.141831587	0.012117823
dipping	As	2	1467	0.092559084	0.023092697	0.139365588	0.010791348
dipping	As	4	0	0.399400449	0.019552579	0.355265041	0.018459767
dipping	As	4	2	0.392301362	0.020235906	0.348952272	0.017398559
dipping	As	4	22	0.322269589	0.04853145	0.289248791	0.030494298
dipping	As	4	42	0.256581487	0.055651089	0.249559556	0.04884237
dipping	As	4	58	0.23485155	0.048828953	0.235808544	0.04646515
dipping	As	4	104	0.162270907	0.035314566	0.172465025	0.038249392
dipping	As	4	135	0.13705558	0.027933939	0.147177522	0.029466175
dipping	As	4	206	0.10366213	0.020502192	0.116086453	0.021946344
dipping	As	4	299	0.085451362	0.014487161	0.097952446	0.017183712
dipping	As	4	582	0.06883157	0.010648804	0.07845691	0.011120345
dipping	As	4	727	0.063473741	0.01031367	0.075570011	0.010763298
dipping	As	4	924	0.05927428	0.011333295	0.07275633	0.010652343
dipping	As	4	1177	0.057931968	0.01161825	0.068638863	0.010180073
dipping	As	4	1467	0.05643822	0.009959545	0.066488324	0.008576394

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	As	6	0	0.402697088	0.024967886	0.26109289	0.018041479
dipping	As	6	2	0.39675905	0.023384327	0.252508269	0.01856433
dipping	As	6	22	0.345660184	0.029731156	0.21400593	0.025421468
dipping	As	6	42	0.283657339	0.037307366	0.185518311	0.031954424
dipping	As	6	58	0.261137502	0.032732198	0.174956762	0.029543251
dipping	As	6	104	0.179362451	0.022971682	0.122336338	0.022575422
dipping	As	6	135	0.148465624	0.019276112	0.104480843	0.018813815
dipping	As	6	206	0.11141758	0.014900364	0.079206404	0.013767687
dipping	As	6	299	0.086783253	0.011818848	0.064939397	0.010875182
dipping	As	6	582	0.066557216	0.007785753	0.049833258	0.006617287
dipping	As	6	727	0.062360281	0.008968848	0.049183803	0.004077253
dipping	As	6	924	0.05690441	0.005126112	0.046982008	0.004842922
dipping	As	6	1177	0.054532651	0.008726905	0.045646277	0.005219021
dipping	As	6	1467	0.053023708	0.007342051	0.043965731	0.005848653
dipping	As	8	0	0.411471531	0.025693902	0.22386702	0.032853653
dipping	As	8	2	0.403492804	0.024159976	0.195383509	0.040923492
dipping	As	8	22	0.355246613	0.029209436	0.17931929	0.03679074
dipping	As	8	42	0.293222554	0.041745067	0.157909488	0.032763289
dipping	As	8	58	0.267278356	0.038198397	0.149745898	0.029530784
dipping	As	8	104	0.1874943	0.026950729	0.115160266	0.022263427
dipping	As	8	135	0.159231469	0.021152501	0.101422035	0.018688929
dipping	As	8	206	0.122278444	0.015704842	0.081872736	0.016559346
dipping	As	8	299	0.098076717	0.012924809	0.068016813	0.01533588
dipping	As	8	582	0.078178396	0.008609509	0.056089379	0.011771731
dipping	As	8	727	0.073699534	0.008282805	0.052389704	0.010951021
dipping	As	8	924	0.067927862	0.010089266	0.049534641	0.011811497
dipping	As	8	1177	0.064609746	0.009212532	0.047790463	0.010845689
dipping	As	8	1467	0.062695144	0.008402542	0.046104697	0.011884173

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Cu	2	0	0.467115535	0.028601348	0.403032487	0.038148405
dipping	Cu	2	2	0.463698361	0.028172766	0.389002536	0.042897899
dipping	Cu	2	22	0.432682505	0.030804406	0.28762112	0.044566787
dipping	Cu	2	42	0.377164538	0.035661257	0.21085894	0.040581825
dipping	Cu	2	58	0.362421218	0.035654921	0.179370495	0.034867757
dipping	Cu	2	104	0.29357973	0.0394044	0.138616135	0.024332316
dipping	Cu	2	135	0.261897155	0.040246778	0.125926497	0.020741873
dipping	Cu	2	206	0.213492553	0.040329836	0.11377046	0.017178656
dipping	Cu	2	299	0.179778117	0.038063701	0.108991713	0.015768676
dipping	Cu	2	582	0.142909584	0.032428157	0.106475949	0.015429398
dipping	Cu	2	727	0.128413525	0.028836369	0.104152544	0.014888349
dipping	Cu	2	924	0.112440325	0.025246208	0.101991618	0.014766257
dipping	Cu	2	1177	0.102654008	0.021010695	0.099230379	0.013798244
dipping	Cu	2	1467	0.091849571	0.020832764	0.096794593	0.013445864
dipping	Cu	4	0	0.339407249	0.054771156	0.348959653	0.030718815
dipping	Cu	4	2	0.325361285	0.052694557	0.335105001	0.034947077
dipping	Cu	4	22	0.287168905	0.046489577	0.235165556	0.037730928
dipping	Cu	4	42	0.242312392	0.043563692	0.172483365	0.044754679
dipping	Cu	4	58	0.220671817	0.039110708	0.145032025	0.038857923
dipping	Cu	4	104	0.158159324	0.028517589	0.103235413	0.024609692
dipping	Cu	4	135	0.135596306	0.023724548	0.091289285	0.018926111
dipping	Cu	4	206	0.110567026	0.017889608	0.078346999	0.015215197
dipping	Cu	4	299	0.101091388	0.015727534	0.071758342	0.012067596
dipping	Cu	4	582	0.091626819	0.014049781	0.066570968	0.010042309
dipping	Cu	4	727	0.088316508	0.012730957	0.063962016	0.009025873
dipping	Cu	4	924	0.086726165	0.010521352	0.062095756	0.00971513
dipping	Cu	4	1177	0.084689412	0.013325575	0.060963501	0.008636173
dipping	Cu	4	1467	0.084531486	0.01127626	0.06028651	0.007676612

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Cu	6	0	0.335894072	0.067843302	0.258472685	0.031765384
dipping	Cu	6	2	0.322220099	0.066340047	0.239177458	0.028951906
dipping	Cu	6	22	0.287749388	0.054350565	0.168061879	0.027635106
dipping	Cu	6	42	0.240131851	0.042908721	0.122620952	0.024727106
dipping	Cu	6	58	0.213776979	0.038142891	0.105412334	0.019344963
dipping	Cu	6	104	0.155455483	0.028021534	0.070823449	0.012394174
dipping	Cu	6	135	0.132884025	0.025703578	0.061984525	0.010649567
dipping	Cu	6	206	0.114305506	0.023692161	0.053306863	0.008488717
dipping	Cu	6	299	0.102137732	0.024571229	0.048404772	0.006132464
dipping	Cu	6	582	0.093984769	0.024728115	0.042506329	0.005146649
dipping	Cu	6	727	0.092276171	0.022071599	0.041638216	0.005529906
dipping	Cu	6	924	0.092602787	0.025097274	0.043187389	0.005836554
dipping	Cu	6	1177	0.090693868	0.023623345	0.042072359	0.00548024
dipping	Cu	6	1467	0.089862882	0.023412446	0.041119908	0.005396522
dipping	Cu	8	0	0.302172752	0.039852636	0.200922093	0.02834882
dipping	Cu	8	2	0.291891454	0.037270649	0.182276566	0.024865506
dipping	Cu	8	22	0.266873882	0.032856324	0.141297485	0.02196048
dipping	Cu	8	42	0.226883997	0.024944349	0.104317001	0.018933348
dipping	Cu	8	58	0.203941973	0.022369259	0.08990156	0.015723388
dipping	Cu	8	104	0.147977585	0.020678059	0.062884383	0.009958598
dipping	Cu	8	135	0.12577185	0.015897162	0.053667455	0.008580466
dipping	Cu	8	206	0.10211159	0.013203494	0.044398536	0.006761854
dipping	Cu	8	299	0.088031703	0.012666199	0.04147023	0.006307635
dipping	Cu	8	582	0.076680986	0.010312944	0.036489499	0.004749902
dipping	Cu	8	727	0.072068254	0.010491896	0.03558586	0.004686799
dipping	Cu	8	924	0.069375139	0.011146862	0.033061843	0.007299095
dipping	Cu	8	1177	0.068435753	0.011348852	0.032913057	0.005640319
dipping	Cu	8	1467	0.066436754	0.01169549	0.033727245	0.004581109

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Fe	2	0	0.386528749	0.129974599	0.44956117	0.057874237
dipping	Fe	2	2	0.382979454	0.129930849	0.440042122	0.061529586
dipping	Fe	2	22	0.353005171	0.120412961	0.336871797	0.077125669
dipping	Fe	2	42	0.312095854	0.104741932	0.251993816	0.067637259
dipping	Fe	2	58	0.298096119	0.100631868	0.223175928	0.062620336
dipping	Fe	2	104	0.23295542	0.083774158	0.177840649	0.046996595
dipping	Fe	2	135	0.203345913	0.075037254	0.161473841	0.045133584
dipping	Fe	2	206	0.159454731	0.061734217	0.145311317	0.038701549
dipping	Fe	2	299	0.128523655	0.051733698	0.137995545	0.031074994
dipping	Fe	2	582	0.099007284	0.040844754	0.132181727	0.029298058
dipping	Fe	2	727	0.088483299	0.035161282	0.130110296	0.027205933
dipping	Fe	2	924	0.07955173	0.03193035	0.126976412	0.026140737
dipping	Fe	2	1177	0.072028612	0.030599593	0.123740558	0.028677878
dipping	Fe	2	1467	0.067879488	0.026927482	0.12493418	0.024376465
dipping	Fe	4	0	0.385764283	0.03027522	0.36908246	0.045386422
dipping	Fe	4	2	0.373382843	0.030069665	0.360860037	0.046248351
dipping	Fe	4	22	0.310037652	0.029701064	0.269112007	0.049355385
dipping	Fe	4	42	0.243054759	0.031016297	0.212695065	0.061179272
dipping	Fe	4	58	0.212057978	0.02752648	0.19064018	0.05874782
dipping	Fe	4	104	0.149326962	0.021158982	0.137488307	0.042950896
dipping	Fe	4	135	0.126811909	0.019440124	0.119867288	0.03895293
dipping	Fe	4	206	0.103421977	0.012419156	0.101615176	0.028910384
dipping	Fe	4	299	0.091464987	0.00826482	0.089856906	0.023746685
dipping	Fe	4	582	0.08195989	0.007438388	0.081572662	0.018027082
dipping	Fe	4	727	0.07806112	0.008914384	0.076190367	0.019374029
dipping	Fe	4	924	0.076074204	0.007462815	0.077130926	0.014730597
dipping	Fe	4	1177	0.07437497	0.007660987	0.075211362	0.014939998
dipping	Fe	4	1467	0.074411052	0.00674911	0.072978446	0.013918494

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Fe	6	0	0.3846284	0.043237341	0.281874443	0.034065065
dipping	Fe	6	2	0.375523202	0.041170571	0.268285659	0.03353332
dipping	Fe	6	22	0.319281314	0.031537644	0.195266386	0.055526698
dipping	Fe	6	42	0.248795502	0.033618618	0.151459194	0.050788959
dipping	Fe	6	58	0.217756192	0.033181139	0.135447922	0.045481387
dipping	Fe	6	104	0.151909141	0.025473787	0.090752827	0.031206448
dipping	Fe	6	135	0.127246948	0.021404887	0.079214723	0.024182475
dipping	Fe	6	206	0.102134215	0.016819379	0.065618832	0.01565131
dipping	Fe	6	299	0.086632325	0.011111556	0.057439211	0.012013554
dipping	Fe	6	582	0.075845326	0.009173268	0.050505389	0.010899292
dipping	Fe	6	727	0.070682727	0.010299072	0.048778934	0.008661417
dipping	Fe	6	924	0.069927485	0.009215044	0.048733778	0.009664728
dipping	Fe	6	1177	0.067782658	0.008417798	0.046314384	0.007539511
dipping	Fe	6	1467	0.06664647	0.007676664	0.047076316	0.006257573
dipping	Fe	8	0	0.386214354	0.044510126	0.222180996	0.036793346
dipping	Fe	8	2	0.372408805	0.042632578	0.205573714	0.036623189
dipping	Fe	8	22	0.32152065	0.029930002	0.166935694	0.04770094
dipping	Fe	8	42	0.255985856	0.025818562	0.132543209	0.049006426
dipping	Fe	8	58	0.222307336	0.024270621	0.119114965	0.043283729
dipping	Fe	8	104	0.153457059	0.019218096	0.078503866	0.036599756
dipping	Fe	8	135	0.130061611	0.017686117	0.067193011	0.030448577
dipping	Fe	8	206	0.105602589	0.016596264	0.058105959	0.012486496
dipping	Fe	8	299	0.093054719	0.011851893	0.049854268	0.008628537
dipping	Fe	8	582	0.082132325	0.012070594	0.043695787	0.006889341
dipping	Fe	8	727	0.079382382	0.013026899	0.041936429	0.004829824
dipping	Fe	8	924	0.077171101	0.014424676	0.040498473	0.006523832
dipping	Fe	8	1177	0.075365976	0.011652708	0.039199123	0.006525322
dipping	Fe	8	1467	0.073620441	0.013182927	0.038699712	0.005665456

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Mn	2	0	0.425888778	0.037929357	0.508457235	0.019652817
dipping	Mn	2	2	0.421352882	0.036889931	0.498590063	0.022079732
dipping	Mn	2	22	0.384101054	0.043780088	0.454573586	0.033347921
dipping	Mn	2	42	0.330940301	0.052706444	0.390378517	0.050302697
dipping	Mn	2	58	0.314044828	0.048651576	0.351213611	0.043651029
dipping	Mn	2	104	0.242427246	0.041917129	0.276177341	0.03537806
dipping	Mn	2	135	0.316846454	0.084361415	0.252520887	0.031457341
dipping	Mn	2	206	0.165140383	0.03414929	0.218183847	0.024560009
dipping	Mn	2	299	0.127514685	0.028969909	0.196699294	0.019251286
dipping	Mn	2	582	0.098362892	0.021868313	0.173722679	0.014385881
dipping	Mn	2	727	0.086377682	0.018561714	0.168097233	0.01482468
dipping	Mn	2	924	0.076762759	0.016199619	0.163002818	0.012804431
dipping	Mn	2	1177	0.068060926	0.015133997	0.160593248	0.012718982
dipping	Mn	2	1467	0.064805896	0.01408653	0.156722078	0.013537384
dipping	Mn	4	0	0.358942366	0.04230043	0.397718671	0.131393737
dipping	Mn	4	2	0.348034031	0.042681295	0.324594523	0.085219988
dipping	Mn	4	22	0.277943265	0.035919403	0.285565528	0.074228292
dipping	Mn	4	42	0.204291605	0.039042204	0.271802549	0.072475124
dipping	Mn	4	58	0.175241024	0.033637159	0.268538631	0.074525131
dipping	Mn	4	104	0.118547298	0.020037311	0.22097625	0.066403957
dipping	Mn	4	135	0.099382233	0.016535627	0.196995682	0.061259344
dipping	Mn	4	206	0.080022754	0.012588323	0.16080353	0.053679522
dipping	Mn	4	299	0.066317395	0.010815116	0.13888947	0.046644443
dipping	Mn	4	582	0.063258771	0.008843041	0.112948059	0.036365934
dipping	Mn	4	727	0.058595711	0.007182472	0.107502774	0.034898197
dipping	Mn	4	924	0.05799454	0.006012461	0.103552118	0.034162983
dipping	Mn	4	1177	0.056971957	0.006506835	0.099651999	0.029864764
dipping	Mn	4	1467	0.056365657	0.007404508	0.093945768	0.027589052

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Mn	6	0	0.355594899	0.041288173	0.237587046	0.119257214
dipping	Mn	6	2	0.343617193	0.038618559	0.189552297	0.068443375
dipping	Mn	6	22	0.270325824	0.022384189	0.163405182	0.061527391
dipping	Mn	6	42	0.197773424	0.027137955	0.156120391	0.062103453
dipping	Mn	6	58	0.172028657	0.024594126	0.153753481	0.058421726
dipping	Mn	6	104	0.117246683	0.017465854	0.123669238	0.048686893
dipping	Mn	6	135	0.098486834	0.013460681	0.112119757	0.04744441
dipping	Mn	6	206	0.077937485	0.009474041	0.08915684	0.042487099
dipping	Mn	6	299	0.069069207	0.006785687	0.07399366	0.035608789
dipping	Mn	6	582	0.062479823	0.00509968	0.059061116	0.026648249
dipping	Mn	6	727	0.057474798	0.005320753	0.056476888	0.028930303
dipping	Mn	6	924	0.05548123	0.007906083	0.0552215	0.029049458
dipping	Mn	6	1177	0.054198865	0.008432309	0.057408426	0.026691123
dipping	Mn	6	1467	0.05265971	0.007417449	0.055751594	0.025529382
dipping	Mn	8	0	0.355142877	0.053632381	-0.000970683	0.122147623
dipping	Mn	8	2	0.343084966	0.053954972	0.011801955	0.055241777
dipping	Mn	8	22	0.283793776	0.033691585	0.011479164	0.043273053
dipping	Mn	8	42	0.213937467	0.027041869	0.008562348	0.041926445
dipping	Mn	8	58	0.184318782	0.026950231	0.007838922	0.042448903
dipping	Mn	8	104	0.130364481	0.019954329	0.007592828	0.039012564
dipping	Mn	8	135	0.110951821	0.015600777	0.004874078	0.037208113
dipping	Mn	8	206	0.091108577	0.009610315	0.009870675	0.025586211
dipping	Mn	8	299	0.079117911	0.011322556	-0.001353608	0.035922105
dipping	Mn	8	582	0.068034744	0.009066585	0.009818107	0.010732279
dipping	Mn	8	727	0.068013684	0.009142194	0.010762694	0.008606293
dipping	Mn	8	924	0.066651279	0.009598569	0.009339037	0.009360501
dipping	Mn	8	1177	0.064835895	0.008364168	0.009708389	0.00970312
dipping	Mn	8	1467	0.063582813	0.010566673	0.007809789	0.009771999

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Sb	2	0	0.421455953	0.039704665	0.457348665	0.023029796
dipping	Sb	2	2	0.41693149	0.040229189	0.446757592	0.026033734
dipping	Sb	2	22	0.394027552	0.041735539	0.338743778	0.057231801
dipping	Sb	2	42	0.359006646	0.041073253	0.269130922	0.055119497
dipping	Sb	2	58	0.349309164	0.037702959	0.24519608	0.046144234
dipping	Sb	2	104	0.294890171	0.031994899	0.191050747	0.02980693
dipping	Sb	2	135	0.267293775	0.030584812	0.174507696	0.02556128
dipping	Sb	2	206	0.227493414	0.03190223	0.155718238	0.019741844
dipping	Sb	2	299	0.194382324	0.033980428	0.145967562	0.016150057
dipping	Sb	2	582	0.160539608	0.035422825	0.139479483	0.015074352
dipping	Sb	2	727	0.140165567	0.034290535	0.136117264	0.015518619
dipping	Sb	2	924	0.123704675	0.032307805	0.133505938	0.015328145
dipping	Sb	2	1177	0.109256515	0.031021847	0.132376141	0.015627104
dipping	Sb	2	1467	0.096286453	0.026352835	0.131204901	0.015504538
dipping	Sb	4	0	0.391818395	0.026357584	0.352778772	0.026058725
dipping	Sb	4	2	0.385785451	0.024667145	0.345544052	0.023914808
dipping	Sb	4	22	0.328544155	0.028564233	0.27814212	0.030511892
dipping	Sb	4	42	0.269136959	0.032258776	0.23811505	0.041848646
dipping	Sb	4	58	0.250286216	0.027846455	0.223968232	0.038037459
dipping	Sb	4	104	0.17400916	0.018275858	0.161152649	0.028929978
dipping	Sb	4	135	0.14510536	0.016162744	0.139515639	0.024310584
dipping	Sb	4	206	0.108814446	0.013006649	0.110206129	0.018168887
dipping	Sb	4	299	0.087315594	0.011729551	0.092913731	0.014864641
dipping	Sb	4	582	0.06732298	0.007554647	0.076551092	0.009619134
dipping	Sb	4	727	0.063081878	0.00824479	0.072453434	0.00948298
dipping	Sb	4	924	0.057206807	0.007009777	0.068756774	0.009084588
dipping	Sb	4	1177	0.054286975	0.006834193	0.066230634	0.007622121
dipping	Sb	4	1467	0.05233471	0.007679855	0.063517531	0.006548339

				Pohlia drummondii		*Physcomitrium patens*	
Treatment	Contaminant	Week	PAR	Fv'/Fm'	sd_Fv'/Fm'	Fv'/Fm'	sd_Fv'/Fm'
dipping	Sb	6	0	0.380210213	0.018609349	0.246746855	0.034425534
dipping	Sb	6	2	0.369841628	0.018372664	0.216812938	0.036220365
dipping	Sb	6	22	0.336481807	0.024758968	0.171047827	0.031649115
dipping	Sb	6	42	0.28691746	0.033954576	0.154657567	0.027312273
dipping	Sb	6	58	0.269047131	0.027663842	0.152575767	0.024371833
dipping	Sb	6	104	0.187255392	0.018366799	0.119280855	0.014972261
dipping	Sb	6	135	0.153691534	0.01491986	0.105499754	0.013016122
dipping	Sb	6	206	0.112738241	0.011252113	0.083641527	0.010738746
dipping	Sb	6	299	0.086806344	0.010275295	0.070698301	0.010133307
dipping	Sb	6	582	0.064294953	0.008369333	0.057783175	0.006226968
dipping	Sb	6	727	0.059591531	0.007377873	0.05425237	0.006907782
dipping	Sb	6	924	0.055220589	0.00651041	0.054121453	0.00654597
dipping	Sb	6	1177	0.050634423	0.008752811	0.05016369	0.006882309
dipping	Sb	6	1467	0.045619869	0.00984894	0.048155778	0.00812782
dipping	Sb	8	0	0.388069239	0.020123565	0.220862963	0.017558113
dipping	Sb	8	2	0.382193391	0.0201662	0.199964104	0.016738308
dipping	Sb	8	22	0.342043936	0.026614407	0.16193482	0.01346462
dipping	Sb	8	42	0.289879569	0.039845309	0.139652209	0.01214126
dipping	Sb	8	58	0.270037467	0.037615808	0.133049111	0.010826622
dipping	Sb	8	104	0.189607809	0.025856651	0.097247556	0.010525205
dipping	Sb	8	135	0.159448161	0.019193942	0.085520533	0.0100971
dipping	Sb	8	206	0.118377562	0.011919756	0.065592888	0.008603568
dipping	Sb	8	299	0.093027498	0.00952986	0.054435967	0.007194713
dipping	Sb	8	582	0.072665698	0.008117367	0.038648246	0.006593997
dipping	Sb	8	727	0.064513453	0.007059791	0.036714312	0.006583574
dipping	Sb	8	924	0.061389784	0.009736803	0.036215851	0.005546262
dipping	Sb	8	1177	0.056459888	0.010499603	0.032675224	0.006536957
dipping	Sb	8	1467	0.05375477	0.012213258	0.0329837	0.004918866